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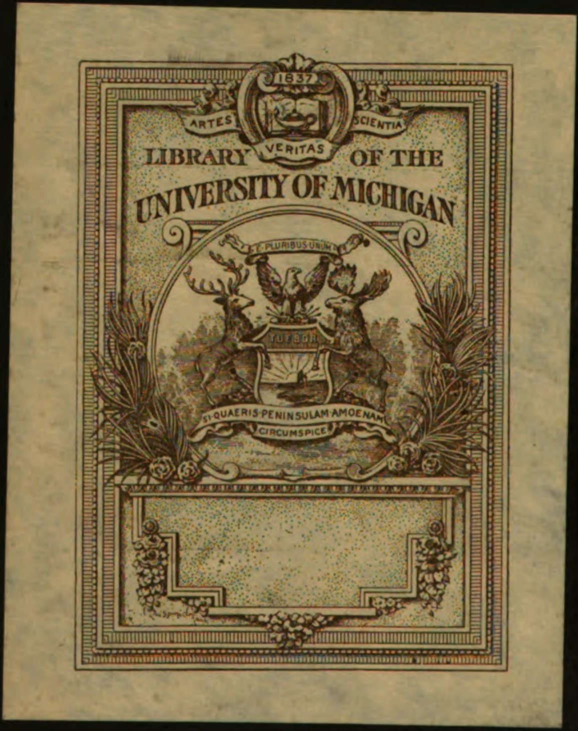

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THE JOURNAL

OF THE

IRON AND STEEL INSTITUTE

Vol. XCI.

EDITED BY

GEORGE C. LLOYD

SECRETARY

PUBLISHED AT THE OFFICES OF THE INSTITUTE
28, VICTORIA STREET, LONDON, S.W.
AND BY
E. & F. N. SPON, LIMITED, 57, HAYMARKET
AND
SPON & CHAMBERLAIN, 123, LIBERTY STREET, NEW YORK
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NAME.	TOWN.	REGIMENT, CORPS, &C.	RANK.
Ablett, C. A.	Montreal	West Mount Rifles, 58th Regiment	Lieutenant
Allen, Cecil	Sheffield	West Riding Division, R.F.A. (Territorial Force)	Staff Captain
Allen, Sir Charles, V.D., J.P.	Sheffield	Royal Field Artillery (Territorial Force)	Colonel (commanding)
Armitage, William J.	Sheffield	York and Lancaster Regiment	Major
Aspinall, J. A. F.	Liverpool	Engineer and Railway Staff Corps, R.E. (Territorial Force)	Lieut.-Colonel
Atkinson, H. Milne	Manchester	Durham Light Infantry	Lieutenant
Bagley, C. H. F.	Stockton-on-Tees	Durham Light Infantry (Reserve Division)	2nd Lieutenant
Bagnall-Wild, R. K.	Farnborough	Aeronautical Inspection Department	Captain (Inspector of Engines)
Bayley, H. Dennis	Nottingham	British Red Cross	Motor Driver
Belaiew, Nicolai T.	Petrograd	......	Colonel
Bell, Maurice L.	Northallerton	Alexandra, Princess of Wales' Own (Yorks. Regiment)	Lieut.-Colonel
Bengough, G. D.	Liverpool	Lancs. and Cheshire Roy. Gar. Artillery	Captain
Bowden, G. Harland	St. Albans, Herts	Royal Fusiliers	Lieut.-Colonel (comdg.)
Boyd, Archibald J.	London	York and Lancaster Regiment (Territorial Force)	Lieutenant
Burnyeat, R. W.	Workington	East Lancashire Brigade, Royal Field Artillery (T.F.)	Captain
Butler, A. I. R.	Newport, Mon.	Royal Field Artillery	Major (comdg.)
Butler, Basil H.	Leeds	West Riding Brigade, R.F.A.	Captain
Butler, Hubert Oswald	Newport	Monmouthshire Regt.	Captain
Campbell, D. F.	London	Royal Naval Volunteer Reserve	A.B.
Cheesewright, W. F.	London	Home Counties Divisional R.E. (Territorial Force)	Lieut.-Colonel
Christie, Malcolm Grahame	Leeds	Royal Flying Corps	2nd Lieutenant
Clough, T. Carter	Sheffield	York and Lancaster Regiment	Major
Coe, Henry J.	Swansea	The Welsh Regiment	2nd Lieutenant
Colver-Glauert, Dr. E.	Sheffield	King's Own (Yorkshire Light Infantry)	Lieutenant

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NAME.	TOWN.	REGIMENT, CORPS, &C.	RANK.
Coombe, L. Jackson	Sheffield	York and Lancaster Regiment	Captain
Cooper, Douglas L.	Middlesbrough	British Red Cross	...
Cowan, J. H.	London	Ordnance Department, War Office	Colonel
Crompton, R. E. B.	London	London Division, Electrical Engineers, R.E. (Territorial Force)	Colonel
Crosland, J. C. H.	Mobberley, Cheshire	Manchester Regiment	Lieut.-Colonel
Darwin, Erasmus[1]	Middlesbrough	4th Yorkshire Regiment	2nd Lieutenant
Davie, Thomas, jun.	Coatbridge	Scottish Rifles	Lieutenant
Dick, Robert D.		Northumbrian R.G.A.	Private
Dore, Alan S. W.	Stourport	Worcestershire Regt. (Territorial Force)	Major
Dorman, Arthur	Yarm, Yorks	4th Yorks Reserve	Captain
Ellison, W. R.	Sheffield	York and Lancaster Regiment	Captain
Else, Stanley C.	Sheffield	York and Lancaster Regiment	2nd Lieutenant
Gray, William Carlaw	Glasgow	3rd Highland Light Infantry	2nd Lieutenant
Gwynne, R. H. B.	Bristol	Royal Garrison Artillery	Lieutenant
Hammond, Joseph	Wollaston, Stourbridge	Royal Warwickshire Regiment	Captain
Hedley, George	Middlesbrough	North Riding (Fortress) Royal Engineers	Captain
Henderson, E. B. Butler	Stafford	Berkshire Yeomanry	Lieutenant
Hopkinson, Allen H.	Huddersfield	Late 5th West Riding Regiment	Now Captain (Recruiting Officer)
Hopkinson, Prof. B.	Cambridge	Cambridge University O.T.C.	Major
Horne, James W.	London	London Scottish	Private
Ingle-Finch, George	London	Royal Garrison Artillery	2nd Lieutenant
Jackson, G. M.	Chesterfield	Lincoln and Leicester Brigade	Brigadier-Commander
Jackson, J. Arthur	Calderbridge, Cumberland	Territorials	Temporary Rank of Major
Jenkins, Robert W.	Rotherham	York and Lancaster Regiment (T. F.)	Captain
Jobson, R. H. T.	Newcastle-upon-Tyne	Northumberland Fusiliers	Captain and Adjutant
Johnson, Herbert A.	Manchester	Manchester Regiment	Lieut.-Colonel (comdg.)
Johnson, Walter L.	Middlesbrough	Durham Light Infantry	Lieut.-Colonel
Kitson, The Hon. R. D.	Leeds	West Yorks. Regiment	Lieutenant
Labrousse, C. J.	Paris	Artillery	Lieutenant
Lees, John	Birmingham	South Staffordshire Regiment	Captain
Lloyd, D. C.	Tettenhall	South Staffordshire Regt. (Territorial Force)	Captain
Longden, A. H.	Stanton-by-Dale	Notts and Derby Regiment (Reserve)	Captain
Lusk, J.	Motherwell	Scottish Rifles	Captain (Transport Officer)
McNeill, H. C.	Ramtek, India	Nagpur Volunteer Rifles	Farrier Sergt.-Major

---

[1] Killed at Ypres, April 23.

NAME.	TOWN.	REGIMENT, CORPS, &C.	RANK.
McWilliam, Dr. Andrew	Kalimati, B.N.R., India	Chota Nagpur Light Horse (Volunteers)	Captain (comdg.)
Marsh, John L.	Sheffield	York and Lancaster Regiment	Captain
Merrett, Prof. W. H.	Wallington, Surrey	London Division Electrical Engineers, R.E. (Territorial Force)	Captain
Monks, Austen J.	Appleton, Cheshire	South Lancashire Regt.	Lieutenant
Monks, F. Remund	Appleton, Cheshire	South Lancashire Regt.	Captain
Morgan, K. P. Vaughan	London	Army Service Corps	Captain
Needham, Joseph G.	Manchester	Army Service Corps (Imperial Service), East Lancashire Territorial Division	Lieut.-Colonel
Pennymore, P. G.	Brierley Hill	Monmouthshire Regt.	Captain and Hon. Major
Phillips, George	London	General Staff, War Office	Major-General Staff Officer
Pollen, Francis H.	London	Royal Navy	Commander
Pollen, Stephen H.	London	A.D.C. to General Sir Ian Hamilton	Captain
Pratt, Arthur E.	London	British Red Cross	...
Randall, Charles R. J.	Barrow-in-Furness	Royal Flying Corps, Naval Wing	Eng. Lieut.-Commander R.N. Squadron Comm. (E) R.N.A.S.
Richards, John A.	London	Admiralty	Engineer-Commander
Rogerson, W. E.	Darlington	Durham Light Infantry	Captain
Rosevere, G. R.	Wolverhampton	Army Ordnance Department	Lieutenant, I.O.M.
Sankey, H. Riall	London	Royal Engineers	Staff Captain
Scott, H. Kilburn	London	Northumberland Hussars	Lieutenant
Seaman, Wilfred A.	Sheffield	West Riding Field Co. Royal Engineers (Territorial Force)	Captain
Selby-Bigge, D. L.	Glasgow	Northumberland Yeomanry	Major
Sidney, Leicester P., Jun.	Middlesbrough	King's Royal Rifle Corps	2nd Lieutenant
Somers, Frank	Birmingham	Worcestershire Regt.	Captain
Speakman, E. M.	London	Royal Flying Corps	Lieutenant
Steel, H., Jun.	Sheffield	York and Lancaster Regiment	Captain
Stewart, V. Beardmore	Glasgow	Highland Light Infantry	2nd Lieutenant
Storey, C. B. C.	Ruabon, Denbighshire	Lancashire Fusiliers	Lieutenant
Struthers, J. G.	Castleford, Yorks.	Royal Naval Air Service	Flight Sub-Lieutenant
Thomas, C. W.	Pedmore, near Stourbridge	Worcestershire Regt.	Major
Thomlinson, William	Seaton Carew	Durham Light Infantry	Lieut.-Colonel
Tofts, C. F.	Jamalpur, India	117th Mahrattas	Lieutenant
Wadham, Walter F. A.	Millwood, Dalton-in-Furness	The King's Own (Royal Lancaster Regiment)	Lieut.-Colonel (comdg.)
Watson, Henry A.	York	Engineer and Railway Staff Corps, Royal Engineers (T. F.)	Major

NAME.	TOWN.	REGIMENT, CORPS, &C.	RANK.
White, James E.[1]	London	East Yorkshire Regt.	Sergeant
Whitehead, Lionel D.	Tredegar, Mon.	Monmouthshire Regt. (Territorial Force)	Lieutenant
Wraith, H. O.	Twickenham, Middlesex	Royal Engineers	Lieutenant
Wright, W. Charles	Blackpill, R.S.O., Glam.	Army Service Corps	Lieut.-Colonel
Wyman, R.	Newport, Mon.	Royal Field Artillery (Territorial Force)	Captain

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[1] Member of office staff of the Iron and Steel Institute.

In respect of members of Belgian, French, and Russian nationality the present list is unfortunately incomplete, owing to the difficulty of obtaining the necessary information.

PREFACE.

In this volume of the *Journal of the Iron and Steel Institute* will be found the Report of the Proceedings of the Forty-sixth Annual Meeting held in London last May, with reprints of the papers read on that occasion, and of the discussions and correspondence thereon, together with the text of the Lecture delivered on the afternoon of May 13, by Professor Hubert, of the University of Liége. It is gratifying to note that, despite the preoccupations occasioned by the war, the average number of papers presented for reading has been fully maintained. By order of the Council, there has also been included, as a matter of historic interest, a report by Professor J. O. Arnold, of Sheffield University, on the Discovery of the Influence of Vanadium on Steel. Obituary notices of deceased members, the Library Report for the half-year ending June 30, and the Record of Progress of the Home and Foreign Iron and Steel Industries have, as usual, been appended.

At the commencement of the volume will be found a list of those members of the Iron and Steel Institute who are at present serving in the armies of the Allies at home and abroad. This list is, unfortunately, less complete than might be desired, owing to the difficulty of ascertaining the names of all those foreign members so serving, and the Editor hopes that those who have special means of information at their disposal will kindly notify him of any omissions, in order that subsequent lists may be rendered more complete.

28 Victoria Street, London, S.W.
July 31, 1915.

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THE

IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

The Forty-sixth Annual General Meeting of the **Iron and Steel Institute** was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday and Friday, May 13 and 14, 1915, Mr. **Arthur Cooper**, LL.D., the immediate Past-President, in the Chair.

The minutes of the previous meeting, held at the offices of the Institute, 28 Victoria Street, London, S.W., on November 19, 1914, were taken as read and signed by the President as a correct record.

Mr. **William Farrar** (Sheffield) and Mr. **John Etherington** (London) were appointed scrutineers of the ballot for the election of new members, and, on the completion of their scrutiny, reported that the following twenty-five candidates for membership had been duly elected:—

Name.	Address.	Proposers.
Bingham, John William	94 Marlcliffe Road, Sheffield.	C. E. Siddall, T. H. Firth, J. F. Melling.
Ferguson, John Martin	Meadowbank, Avon Street, Motherwell.	D. Colville, D. M. Maclay, D. J. Pinkerton.
Gille, Carl Helmer .	Fiskars, Finland.	A. Lindsay von Julin, Albert von Julin, Arthur Cooper.
Gladwyn, Sidney Charles, Wh. Ex. Assoc., M.Inst.C.E.	63 Quentin Road, Blackheath, London, S.E.	Samuel Osborn, James Renton, Arnold Pye-Smith.

Name.	Address.	Proposers.
Gowan, Arthur Byram	7 Brandling Park, Newcastle-on-Tyne.	Geo. Ainsworth, Illtyd Williams, S. L. Worton.
Holder, James Henry	Chinese Government Railway, Tongshan, North China.	John Etherington, Joseph Adamson, Andrew Brown.
Honda, Professor Kôtarô	Komegafukuro, Sendai, Japan.	Sir R. A. Hadfield, I. B. Milne, Ernest Ott.
Ishikawa, Fukusaburo	Imperial Japanese Navy Office, Broadway Court, Westminster, London, S.W.	H. C. H. Carpenter, C. A. Edwards, J. H. Andrew.
Kendrick, Joseph . .	29 Oakdale Road, Sheffield.	C. E. Siddall, T. H. Firth, J. F. Melling.
Kikkawa, Haruju .	3 Cecil Street, Chorlton-on-Medlock, Manchester.	H. C. H. Carpenter, C. A. Edwards, J. H. Andrew.
Mikolajczak - Sepulchre, Victor	17 Maresfield Gardens, Hampstead, London, N.W., and Marche-les-Dames, Belgium.	H. Hubert, H. de Gorski, Ralph G. Scott.
Mizutani, Admiral Yoshihiko	The Japan Steel Works, Muroran, Hokkaido, Japan.	J. M. Gledhill, Arthur Cooper, J. C. Cuninghame.
Mountain, William Chas., M.I.Mech.E.	Sun Buildings, Collingwood Street, Newcastle-on-Tyne.	Geo. Ainsworth, J. Scott, J. R. Williams.
Owen, George William	57 Princess Street, Manchester.	George Hatton, J. W. Trowsdale, J. Kent Smith.
Russell, Frank . .	3 Highland Grove, Worksop.	Ralph G. Scott, F. M. Parkin, F. M. Osborn.
Shore, Albert F. . .	555 West Twenty-second Street, New York City, U.S.A.	Sir R. A. Hadfield, A. G. M. Jack, Ernest Ott.
Sidney, Leicester Philip, jun.	76 York Mansions, Battersea Park, London, S.W.	Arthur Cooper, Sir R. A. Hadfield, Frederick Mills.
Skinner, Orville Campbell, B.Sc.	Standard Steel Works Company, Burnham, Pennsylvania, U.S.A.	S. T. Wellman, A. Ladd Colby, Lawford H. Fry.
Smith, Richard Henry	The University, Birmingham.	T. Turner, O. F. Hudson, H. I. Coe.
Smith, Robert Low, F.C.S.	31 Dunvegan Gardens, Eltham, London, S.E.	R. J. Redding, Albert Humphries, F. C. W. Dean.
Trevelyan, Freeman .	Elswick Works, Newcastle-on-Tyne.	J. M. Gledhill, Arthur Cooper, C. J. Bagley.
Trubey, George . .	Sakchi, Kalimati, B.N.R., India.	Richard Knowles, A. McWilliam, I. B. Milne.
Tyshnoff, Vsevolod .	Ekateringofsky, Prospect 63, Petrograd, Russia.	D. Tschernoff, M. Pavloff, Sir R. A. Hadfield.
Weitzenkorn, Joseph W.	Crucible Steel Company of America, Pittsburg, Pa.	G. W. Sargent, C. F. W. Rys, H. P. Tiemann.
West, Walter . . .	183 Eglinton Rd., Plumstead, London, S.E.	R. J. Redding, J. Newton Friend, J. Lloyd Bentley.

Mr. **Arthur Cooper**, in opening the Meeting, said the Council very much regretted that the President was not able to attend the meetings for reasons which would be understood on referring to the Report of Council, but they were glad to believe that Mr. Greiner was still enjoying good health. In a recent communication received from him accompanying the note which would shortly be read, and which it was proposed to regard as an addendum to his Address of last year, the President said that he sent the communication more in the nature of a reminder that his colleagues and Mr. Lloyd were constantly in his thoughts, and he asked that his most friendly greetings should be conveyed to the members, with an expression of profound regret at his inability properly to comply with the duties with which he had been charged.

He (Mr. Cooper) might also mention that a short time ago it had come to the knowledge of the Council that an Association of Belgian Engineers in London had been formed, and it had given the Council very great pleasure to issue invitations to all its members to attend the meetings of the Institute. They cordially welcomed all those who had been able to do so.

The following Report of the Council upon the Proceedings of the Institute during the year 1914 was read in abstract by the Secretary:—

REPORT OF COUNCIL.[1]

THE Council have the pleasure of submitting to the Members of the Iron and Steel Institute, on the occasion of this, the Forty-sixth Annual General Meeting, the Annual Report of the progress of the work of the Institute during the year ending December 31, 1914.

THE PRESIDENT.

Since the beginning of the war in August, direct communication with Mr. Adolphe Greiner, the President, has unfortunately been impossible; but from time to time news concerning him and his family have been received through various channels. During the siege of Liége, and from that time onwards, Mr. Greiner has remained at his post, continually encouraging with his unfailing spirit the members of the staff of the Cockerill Company and his workmen, and organising means for the alleviation of the distress of the large industrial population dependent on the Company for employment. Notwithstanding the many anxieties through which he has passed, the latest news indicates that his activities are undiminished, and that he and his family are in good health.

In the enforced absence of Mr. Greiner, Mr. Arthur Cooper, the immediate Past-President, has added to his many services to the Institute by kindly performing the duties of the Presidency.

ROLL OF THE INSTITUTE.

The number of new Members who were elected during the year is 116. The total membership of the Institute on December 31, 1914, was as follows:—

Patron	1
Honorary Members	7
Life Members	65
Ordinary Members	2013
Total	2086

Among these there are no fewer than 632 foreign Members, of whom, at the outbreak of the war in August, 101 were of German, Austrian, or Hungarian nationality. Since August there have been two deaths and nineteen resignations of German Members, leaving eighty names still on the register. The Council have under consideration the position of these Members.

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[1] As amended at the meeting (see pp. 25 and 29).

It was further decided that the names of Members of the Institute on active service in the armies of the Allied Nations should be enrolled in a special list[1] for preservation in the records of the Institute, and published from time to time in the *Journal.*

DISTINCTIONS CONFERRED UPON MEMBERS OF THE INSTITUTE.

The Council take this opportunity of offering their congratulations to several Members of the Institute who have had distinctions conferred upon them :—

Dr. Thomas Kirk Rose, Chemist and Assayer at the Royal Mint, and Mr. John Cowan of Edinburgh, have each had the honour of knighthood conferred upon them; Colonel S. M. Renny has been created Companion of the Order of the Indian Empire; Mr. Tord Magnuson has been created a Knight Commander of the Order of Vasa; Mr. Charles F. Rand has received the Order of Isabela la Católica and the Grand Cross of a Knight Commander of Spain; Dr. J. E. Stead, *Vice-President*, has had conferred upon him the honorary degree of Doctor of Science of the University of Manchester; Mr. W. R. Lysaght has been appointed High Sheriff of Monmouthshire; Mr. W. H. Ellis has been elected Master Cutler of Sheffield; and Mr. C. A. Edwards has been appointed to the Chair of Metallurgy and Metallography at the Manchester University.

During the year 1914 the Institute has had to record the deaths of several well-known Members, the complete list comprising the following thirty-five names :—

	1914.
Merthyr of Senghenydd, The Right Hon. Lord (Aberdare), *Vice-President*	August 27.
Bayliss, Thomas Richard (Birmingham)	July 24.
Butler, T. F. (Barrow-in-Furness)	June 16.
*Cliff, Joseph (Lincoln)	...
Cooper, Arthur Henry (Partington)	March 16.

* Denotes Original Member.

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[1] See note on p. 15.

Dawson, Robert (Stalybridge)	April 27.
Evans, John (Dowlais)	February 12.
Freeborough, Benjamin (Sheffield)	January 14.
Frielinghaus, G. (Essen, Germany)	November 11
Gilmour, James Anderson (Kilmarnock)	January 14.
*Kirk, Henry (Workington)	July 18.
Kirkaldy, William George (London)	April 10.
Leadbeater, Edwin (Sheffield)	June 9.
Lodin, Professor Arthur (Paris)	...
Longridge, Robert Bewick (Manchester)	July 31.
Lürmann, Fritz (Berlin)	August 30.
MacLennan, Joseph (Bilbao)	March 1.
Magery, Maurice (Namur, Belgium)	October 9.
Molander, Axel (Stockholm)	February 24.
Mottram, Sir Richard (Selford)	April 4.
*Parry, John (London)	December 2.
Péters, Maurice (Ougrée, Belgium)	January 6.
Ponthière, Professor Honoré (Louvain)	August 25.
Putnam, Arthur (Darlington)	May 11.
Ridley, J. Cartmell (Newcastle-on-Tyne)	December 27.
Riley, Edward (Marlow), *Bessemer Medallist*	September 13.
Rogerson, Harry (Airdrie)	January 24.
Rogerson, William E. (Darlington)	November 13.
Sauvée, Albert (London)	September 30.
Smith, Frederick (Salford)	August 27.
Sturrock, David (Glasgow)	February 25.
Tasker, John Henry Royle (Sheffield)	January 17.
Wahlberg, *Captain* Gustaf (Bofors)	February 16.
While, Adolf Swain (Hughesoffka, Russia)	November 21.
Wood, Stuart (Philadelphia)	March 9.

The deaths of the following two Members occurred in 1913, but were not noted in the Council Report for that year:—

Fould-Dupont, A. (Pompey, France)	October 8.
Wilson-Dickson, John Gordon (Newcastle-on-Tyne)	February 23.

Lord Merthyr's association with the Institute dates nearly from its establishment. He became a member in 1871, was elected a Member of Council in 1890, and a Vice-President in 1897. He also held high office in many other learned and educational institutions, having been President of the University College of South Wales and Monmouthshire, President of the South Wales Institute of Engineers, of the Mining Association of Great Britain, and of the Institution of Mining Engineers.

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* Denotes Original Member.

Professor Honoré Ponthière, aged 70, who was Professor of Metallurgy at Louvain University, was shot, together with his son, by the enemy at Hastières in South Belgium, on or about August 20, 1914.

Full particulars of the careers of these and other deceased members will be found in the volumes of the Journal for 1914.

In consequence of the non-payment of subscriptions, the names of twenty-six members have been removed from the list, and there have been seventy resignations.

FINANCE.

The statement of accounts for the year 1914, verified by the auditors, is now submitted by the Honorary Treasurer. It will be observed that the total receipts for the year amount to £6310, 8*s.* and the expenditure to £5805, 16*s.* 1*d.* There is thus an excess of income over expenditure amounting to £504, 11*s.* 11*d.* The corresponding figures for recent years are as follows:—

	Receipts.			Expenditure.		
	£	s.	d.	£	s.	d.
1909 . . .	6356	10	0	5451	16	9
1910 . . .	6428	5	5	5811	18	9
1911 . . .	6399	3	11	6625	19	7
1912 . . .	6483	15	6	5793	7	8
1913 . . .	6591	19	7	6273	6	5

MEETINGS.

The Annual Meeting was held on May 7 and 8 in the Hall of the Institution of Civil Engineers, Great George Street, Westminster, by kind permission of the Council of that Institution. The long list of papers presented at that Meeting necessitated the holding of three sessions, on the morning and afternoon of Thursday, May 7, and on the morning of Friday, May 8, respectively.

The Annual Dinner was held on the evening of May 7 at the Connaught Rooms, Great Queen Street, London, W.C., the Chair being taken by Mr. Adolphe Greiner, the President of the Institute.

The attendance numbered about 400, and the principal speakers were Sir Frederick Donaldson, K.C.B.; Mr. James A. Farrell, President of the United States Steel Corporation; Mr. R. Pinot, the Secretary of the Comité des Forges de France; Sir Hugh Bell, Bart., Past-President; His Excellency Count de Lalaing, Belgian Minister; the Honourable Mr. Justice Darling, Sir George R. Askwith, K.C.B., and Sir John S. Randles, M.P.

By the kind invitation of the Comité des Forges de France, arrangements had been made to hold the Autumn Meeting of the Iron and Steel Institute in Paris on Thursday, Friday, and Saturday, September 17, 18, and 19, to be followed by a visit to Nancy, and excursions from that town to the ironworks and ore fields of Lorraine. The forms received in reply to the circular sent out to Members showed that the attendance to be expected was unusually high for an Autumn Meeting, no fewer than 390 members, many of whom expected to be accompanied by ladies, having intimated their intention of taking part in the meeting. The final circular was posted to Members on July 22, but about that time the political situation in Europe developed a serious aspect, culminating within a few days in the outbreak of the great war. The Comité des Forges was obliged to cancel all arrangements for the Autumn Meeting of the Institute in France, and in the circumstances the Council decided that, as a matter of courtesy to the prospective hosts of the Institute, no alternative meeting should be held in this country for the reading and discussion of papers offered for the Paris meeting. As, however, a statutory autumn meeting was required by the rules for dealing with certain formal business, notice was given on October 27 that such a meeting would be held on Thursday, November 19, at the offices of the Institute, 28 Victoria Street, London, S.W. In the unavoidable absence of Mr. Adolphe Greiner, President, the Chair was taken by Mr. Arthur Cooper, the immediate Past-President. A report of the proceedings will be found in the Minutes of Proceedings published in the volume No. II. of the Journal for 1914.

Thirty papers were contributed to the Proceedings of the Institute during the year, and have been printed in the Journal, together with the discussion and correspondence thereon. The titles of these papers are as follows :—

1. J. O. ARNOLD, D.Met., F.R.S., and G. R. BOLSOVER (Sheffield University): "The Forms in which Sulphides may exist in Steel Ingots."
2. CARL BENEDICKS, Ph.D. (University of Stockholm): "Experiments on Allotropy of Iron; Behaviour of Ferro-magnetic Mixtures; Dilatation of Pure Iron."

3. A. **Bose** (Ranchi, Bengal, India): "Recent Developments of the Iron and Steel Industry in India.".
4. E. D. **Campbell** (Ann Arbor, Michigan): "A Contribution to the Theory of Hardening and the Constitution of Steel."
5. C. **Chappell** (Sheffield): "The Recrystallisation of Deformed Iron."
6. G. **Stanley Cooper**, B.Sc. (Sheffield): "The Bye-product Coking Industry and its Relation to the Manufacture of Iron and Steel."
7. **Lawrence Dufty**, B.Met. (Sheffield): "The Determination of Cobalt in High-speed Steels."
8. C. A. **Edwards**, D.Sc. (Manchester University), and H. C. H. **Carpenter**, M.A., Ph.D. (London): "The Hardening of Metals, with Special Reference to Iron and its Alloys."
9. J. **Newton Friend**, D.Sc., and C. W, **Marshall** (Worcester): "The Influence of Molybdenum upon the Corrodibility of Steel."
10. H. C. **Greenwood** (Manchester): "Note on a Curious Case of Decarburisation during the Hardening of Steel Dies."
11. L. **Guillet**, D.Sc. (Paris): "Electrolytic Iron: its Manufacture, Properties, and Uses."
12. Sir **Robert A. Hadfield**, D.Sc., F.R.S. (London), and B. **Hopkinson**, M.A., F.R.S. (Cambridge): "The Magnetic and Mechanical Properties of Manganese Steel."
13. **George Hailstone** (Birmingham): "The Transverse Testing of Cast Iron."
14. H. L. **Heathcote** (Coventry): "Some Recent Improvements in Case Hardening Practice."
15. S. A. **Houghton** (Glasgow): "Failures of Heavy Boiler Shell Plates."
16. **Ernest Humbert** and **Axel Hethey**, B.Sc. (London): "The Production of Steel direct from Iron Ore."
17. **Walter L. Johnson** (Middlesbrough): "Utilisation of Heat contained in Slag."
18. N. **Kapp** (Birmingham): "Mechanical Charging of Blast-furnaces."
19. **Andrew M'Cance**, B.Sc. (Glasgow): "A Contribution to the Theory of Hardening."
20. G. **Misson** (Seraing): "The Colorimetric Estimation of Sulphur in Pig Iron and Steels, by Means of Paper Impregnated with a Solution of Arsenious Anhydride in Hydrochloric Acid."
21. **Fritz Müller** (Brebach, Germany): "The Development of Dry-cleaning in Blast-furnace Gas Purification."
22. **Paul Nicou** (Paris): "The Iron Ore Deposits of Eastern and Western France."
23. H. **de Nolly** and L. **Veyret** (Saint Chamond, Loire): "Note on the Transformations of Steel."
24. J. A. **Pickard**, B.Sc., and F. M. **Potter** (London): "The Oxygen Content of Open-hearth Steel."
25. A. M. **Portevin** (Paris): "The Decarburisation of Steels in the Salt Baths used for Heating prior to Hardening."
26. A. M. **Portevin** and V. **Bernard** (Paris): "The Influence of Coalescence on the Mechanical Properties of Steel and on Alloys."
27. W. **Rosenhain**, D.Sc., F.R.S., and J. L. **Haughton** (London): "A New Reagent for Etching Mild Steel."
28. **Axel Sahlin** (Brussels): "The Use of Liquid Ferro-manganese in the Steel Processes."

29. Dr. F. SCHUSTER (Witkowitz): "The Talbot Process in Comparison with other Open-hearth Processes."

30. A. SPANNAGEL, D.Ing. (Neunkirchen-Saar, Germany): "A New Process for Heating Blast-furnace Stoves."

PUBLICATIONS.

During the past year two cloth-bound volumes of the Journal of the Institute have been issued, together with the List of Members, a volume containing the Carnegie Scholarship Memoirs presented in 1914, and a new classified catalogue of the works of reference and of the Journals, Proceedings, and technical publications contained in the library of the Institute. These publications comprise 1820 pages of printed matter and 87 plates, in addition to numerous illustrations in the text.

In addition to the papers read at the Spring Meeting, and to those presented at the Autumn Meeting, which latter, owing to the peculiar circumstances then prevailing, were taken as read and discussed by correspondence only, abstracts and references to nearly two thousand articles and memoirs relating to the iron and steel industries published in the transactions of kindred Institutions and Societies at home and abroad, and of the principal foreign countries engaged in the industry, have been compiled and published in the Notes on the Progress of Home and Foreign Iron and Steel Industries, in order to supply Members with as complete a bibliography of the industry as possible. In the collection and compilation of those abstracts over three hundred different periodicals have been systematically searched, and the information rendered available to the Members of the Institute. Most of the original sources of information are filed in the Institute library, and Members can avail themselves at first hand with information on the subjects they desire to investigate.

By the special permission of his Majesty's Government, the Institute continues to receive the principal technical papers and transactions of societies published in enemy countries, but it has not been possible to maintain the regular supply of all such periodicals. It is hoped that opportunity may be found after the war to complete the files of these publications.

MEDALS AND RESEARCH SCHOLARSHIPS.

The Bessemer Gold Medal for the year 1914 was presented to Mr. Edward Riley, in recognition of the valuable services he rendered to the advancement of the metallurgy of iron and steel. Unfortunately Mr. Riley was not well enough to receive it in person, and his partner, Mr. F. W. Harbord, kindly consented to receive it on his behalf The Council regret to have to record that Mr. Riley's illness terminated fatally, and his death occurred on September 13.

The Andrew Carnegie Gold Medal for the year 1913 was awarded to Dr. Thomas Swinden, of Sheffield, for his valuable researches on molybdenum steels, carried out in connection with the Carnegie Scholarship Award made to him in 1909.

Twenty-six applications for awards of Carnegie Research Scholarships were received from candidates. After careful consideration of the qualifications of the candidates, seven scholarships, each of the value of £100, tenable for one year, were awarded respectively to Messrs. H. M. Boylston (Cambridge, Mass.); Cyril Chappell (Sheffield); H. B. Cronshaw (Cambridge); J. W. Donaldson (Motherwell); R. S. G. Knight (London); F. C. A. H. Lantsberry (Birmingham); and A. Sander (Karlsruhe). Further grants of the value of £50 each were awarded to Messrs. J. H. Andrew (Manchester), George Hailstone (Smethwick), and J. A. Pickard (London).

Particulars of the awards and short notices of the careers of the successful candidates have been published in the Journal, No. I., 1914, and the usual notices containing the conditions under which the scholarships are awarded, printed in seven languages, have been circulated as usual, subject to the necessary limitations imposed by the war.

In order to assist candidates in selecting subjects suitable for investigation, lists have also been drawn up and circulated.

The reports of the work done by Carnegie Scholars are published in the Carnegie Scholarship Memoirs, the volume issued in the year 1914 containing the following Reports:—

"Methods of Transport of Raw Material in the Iron Industry, with Special Reference to the Cost of Production of Pig Iron," by F. J. Apfelstedt (Dresden); "Electric Furnaces for Heating Steel," by A. Hirsch (New York); "Rotary Bend Tests, Alternating Bend Tests, and Repeated Shock Tests," by E. Nusbaumer (Paris); "Influence of Riveting on the Stresses in the Rivet, and on the Strength Properties of the Rivet Material," by H. Rudeloff (Gross-Lichterfelde, Berlin); "The Gases occluded in Liquid Steel" (Interim Report), by L. Baraduc-Muller (Paris); "An Examination of Firebricks and some other Technical Refractory Materials," by W. Hamilton Patterson (Birkenhead).

LIBRARY AND OFFICES.

The attendances at the Institute Reading-room and Library during the past year have been well sustained, and the Council have much pleasure in recording the fact that the Library has afforded a meeting-place for many Belgian and French Members of the Institute, who, owing to the war, have become temporarily resident in this country, and also for Members of allied Societies and Institutes in both countries who have found themselves similarly circumstanced. A register of these attendances, containing over forty names and addresses, has been compiled, showing that the action of the Council has been thoroughly appreciated by those to whom these privileges have been extended.

Considerable additions have been made to the Reference Library, both by presentation and by purchase. Amongst the former are "La Silice et les Silicates," by H. Le Chatelier, and "An Introduction to the Study of Physical Metallurgy," by Walter Rosenhain. The acquisitions by purchase include: "Electro-plating," by W. R. Barclay and C. H. Hainsworth; "A Text-book of Assaying," by C. and J. J. Beringer; "A Handbook on Japanning, Tinning, and Galvanising," by W. N. Brown; "Gas Analysis," by L. M. Dennis; "A Practical Manual of Autogenous Welding," by R. Granjon and P. Rosemberg; "General Metallurgy," by H. O. Hofman; "Metallurgical Analysis," by N. W. Lord and D. J. Demorest; "Coal-tar and Ammonia," by George Lunge; "The Microscopic Analysis of Metals" (second edition), by F. Osmond; "The Science of Burning Liquid Fuel," by W. N. Best; "Solid, Liquid, and Gaseous Fuel," by J. S. S. Brame; "Welding and Cutting Metals by the Aid of Gases or Electricity," by L. A. Groth; "The Steel Foundry," by J. H. Hall; "Treatise on the Electro Deposition of Metals," by G. Langbein; "Alloys and their Industrial Application" (second edition), by E. F. Law; "Steel, its Selection, Annealing, Hardening, and Tempering" (fourth edition), by E. R. Markham; "Treatise on Quantitative Inorganic Analysis," by J. W. Mellor; "Steel Rails, their History, Properties, Strength, and Manufacture," by W. H. Sellew; "The Electric Furnace," by A. Stansfield; "Coal Tar Distillation and Tar Products," by A. R. Warnes.

Complete lists of the Library additions will be found in the two volumes of the Journal for the year.

In order to render more generally available the various text-books, proceedings of scientific societies, and periodicals contained in the Library of the Institute, a new Catalogue has been published, the old Catalogue, published in 1884, having long since been out of date. The Catalogue comprises a Name Index and a classified list of the books.

The Council earnestly request Members who have published works relating to the metallurgy of iron and steel to present copies to the Institute Library, and thus to co-operate in the endeavour to render the Library as complete as possible. All such presentations are gratefully appreciated, and will be duly acknowledged in the Journal.

During the year the rooms of the Institute have been repainted and decorated throughout.

APPOINTMENT OF REPRESENTATIVES.

The President continues to represent the Institute on the General Committee of the Royal Society for administering the Government Grant for Scientific Investigations. On the Board of the National Physical Laboratory the representatives of the Institute are Sir Hugh Bell, Bart., and Mr. W. H. Ellis. Sir Hugh Bell has also continued to act as representative on the Board of Governors of the Imperial College of Science and Technology. On the Engineering Standards Committee the Institute is represented by Mr. Arthur Cooper, Mr. George Ainsworth, and Mr. Illtyd Williams, while Mr. Charles Dorman and Mr. R. E. E. Spencer have been nominated by the Council as Members respectively of the Engineering Standards Sub-Committee for the Standardisation of Galvanised Sheets, and the Sub-Committee for Special Steels for Motor Car Construction. Mr. Illtyd Williams served as representative on the General Engineering Research Committee of the Institution of Mechanical Engineers. Sir William Beardmore, Bart., and Mr. George Ainsworth have continued to act as representatives of the Institute on the Technical Committee of Lloyd's Register of British and Foreign Shipping. Dr. J. E. Stead, F.R.S., represents the Institute on the Advisory Committee of the Royal School of Mines; Sir Robert Hadfield, F.R.S., serves as representative of the Institute on the Court of the University of Sheffield, and also on the Home Consulting Committee of Hong-Kong University, and Mr. W. Peter Rylands has been appointed to act in a similar capacity on the Court of the University of Liverpool. Mr. Arthur Cooper, Lord Airedale, Sir Robert Hadfield, and Mr. P. C. Gilchrist have continued to serve on the Sir William White Memorial Consultative Committee.

INTERNATIONAL CONGRESS OF MINING, METALLURGY, &c.

On the Organising Committee of the Sixth International Congress of Mining, Metallurgy, Applied Mechanics, and Practical Geology, the Institute was represented by Mr. Arthur Cooper, who acted as Chairman of the Committee, Sir Hugh Bell, Bart., who was appointed Honorary Treasurer of the Congress, Sir Robert Hadfield, F.R.S., Mr. George Ainsworth, and Professor Henry Louis. When war broke out it became apparent that it would be impossible to hold the Congress in 1915, as originally intended, and the Committee decided in September to suspend the work of organisation and to defer the holding of the Congress *sine die*.

ELECTION OF MEMBERS OF COUNCIL.

In June 1914 Mr. J. M. Gledhill was elected a Vice-President in succession to Mr. Adolphe Greiner, on the election of the latter as President of the Institute. Mr. A. Lamberton and Mr. W. H. Hewlett were elected Vice-Presidents in November to fill the vacancies created, in one case, by the death of Lord Merthyr, and, in the other, by the retirement of Mr. J. M. While, who resigned in 1914. On the outbreak of war, Mr. F. Springorum resigned his membership of the Institute, thereby vacating his seat on the Council.

The Institute has further to record the deaths of Mr. Arthur Keen and Mr. William Evans, Vice-Presidents, which occurred respectively in January and February 1915, and, in succession to them, Mr. C. P. E. Schneider and Mr. W. H. Ellis have been elected Vice-Presidents.

In consequence of these changes, six vacancies arose on the Council, which have been filled by the election of Mr. Frederick Mills (Ebbw Vale), Professor Henry Le Chatelier (Paris), Sir John S. Randles, M.P. (Keswick), Mr. W. R. Lysaght (Newport), Mr. Gustave Trasenster (Ougrée, Belgium), and Colonel William Charles Wright, who take the places vacated respectively by Mr. Gledhill, Mr. Lamberton, Mr. Hewlett, Mr. Schneider, and Mr. Ellis, elected Vice-Presidents, and of Mr. Springorum, resigned.

The Vice-Presidents and Members of Council whose names, in accordance with Bye-law 10, were announced at the last General Meeting as being due to retire at the Annual Meeting are:—

Vice-Presidents, Dr. J. E. Stead, Mr. G. Ainsworth, and Mr. J. M. Gledhill. *Members of Council*, Mr. A. Lamberton, Mr. W. H. Hewlett, Mr. C. P. E. Schneider, Mr. W. H. Ellis, and Mr. C. J. Bagley. Mr. Lamberton, Mr. Hewlett, Mr. Schneider, and Mr. Ellis having in the meantime been elected Vice-Presidents, the list of those Members due to retire now consists of Professor Henry Le Chatelier, Sir John S. Randles, Mr. W. R. Lysaght, Mr. C. J. Bagley, and Mr. J. H. Darby. No other Members having been nominated up to one month previous to this meeting, in response to the announcement made at the last meeting, the retiring members, subject to the changes specified, are presented for re-election.

[NOTE.—In the Draft Report of Council presented at the Meeting a list was given of Members of the Institute serving in His Majesty's Forces. This list will be found printed at the beginning of the present volume.—ED.]

Mr. G. **Mure Ritchie** (London) said that before the Report was adopted he desired to refer to a sentence which occurred in the Draft Report, namely, that it had "been decided to take no active steps for the removal of their names from the list of members," the reference being to German and Austrian members of the Institute. He desired to ask if he would be in order in moving a resolution.

Mr. **Cooper** having replied in the affirmative,

Mr. **Mure Ritchie** said that he would be pleased to do so if the Chairman would let him know the proper time at which to bring the matter up again.

HON. TREASURER'S FINANCIAL STATEMENT.

Sir **William Beardmore**, Hon. Treasurer, said he had pleasure in submitting to the Meeting his Report on the accounts for the year 1914, the usual printed statement of which was in the members' hands. The revenue, compared with that of the previous year, showed a slight falling off. Altogether the receipts amounted to £6310 as against £6592 in 1913, the difference being £282. The expenditure, however, was also correspondingly lower, being £5805 against £6273, or £468 less than in 1913. There was, therefore notwithstanding the lessened income, a net balance of £504 to carry forward. The diminution in the receipts was principally due to the smaller number of life compositions taken up in 1914, and also to the reduced proceeds of the Journal sales, both of which items were always more or less subject to fluctuation. The lower expenditure was accounted for by the fact that the Autumn Meeting was not held on the ordinary scale, which had the further result that the Journal publishing expenses were also somewhat reduced. The income of the Carnegie Scholarship Fund was £1000, being lower by £12 than in 1913. The amount expended in grants to scholars, translations, printing, and administration was £1254, which had not only absorbed the balance of £82 carried forward from the previous year, but left a deficit in the account of the Fund of £103. During 1914 the investments on account of life compositions were increased by the purchase of £335 London Electric Railway 4 per cent. Perpetual Debenture Stock; £335 Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock; £335 North British Railway 4½ per cent. Irredeemable Preference Stock, purchased at a total cost of £1010, which brought the funds invested on that account up to £2264. The total invested funds of the Institute now amounted to £16,472, which in 1914 yielded to the Institute an income of £552.

Mr. G. G. S. Grundy (Leeds), in proposing a hearty vote of thanks to the President and Council for the work they had done during the past twelve months, said he was sure all the members were extremely glad to hear that Mr. Adolphe Greiner was very well, that his activities were undiminished, and that he and his family were in good health. He also wished to allude to the same point to which Mr. Mure Ritchie had already called attention. He sincerely hoped the Council would reconsider their decision to take no active step for the removal of certain names from the list of members. In particular he drew attention to the list of the Honorary Members of the Institute, and again expressed the hope that the Council would reconsider their decision.

The resolution of thanks having been carried by acclamation,

Mr. Cooper, on behalf of the Council, thanked Mr. Grundy for the kind vote of thanks proposed. He had particularly noted what both Mr. Mure Ritchie and Mr. Grundy had said with regard to the paragraph in the Report of the Council relating to the names of enemy members. The Council had been by no means idle in the matter. Since the Report had been printed the solicitors of the Institute had been consulted, and the Council had again had the matter under consideration that morning. He assured the members that anything that could be done in the interests of the Institute would be done. He hoped the members would not think it necessary to press the matter any further at the present meeting. If it would

THE IRON AND STEEL INSTITUTE.

ACCOUNT OF INCOME AND EXPENDITURE FOR THE YEAR ENDED DECEMBER 31, 1914.

INCOME.

To Entrance Fees		£222 12 0
,, Annual Subscriptions		4,154 10 8
,, Life Compositions		31 10 0
,, Journal Sales		273 10 7
,, Interest on Investments, less Tax		552 11 7
,, Income Tax recovered		31 9 2
,, Bessemer Medal Fund :—		
Interest on Investment, less Tax	£15 1 4	
Income Tax recovered	0 18 8	
		16 0 0
,, Interest on Deposit		25 7 2
,, Sundry Receipts		2 10 1
,, Carnegie Scholarship Fund :—		
Interest on Bonds, less Tax	£845 15 10	
Do. Investments, less Tax	93 9 6	
Income Tax recovered	61 1 5	
		1,000 6 9
		£6,310 8 0

EXPENDITURE.

By Salaries (including Overtime)		£1,842 11 11
,, Office Rent, Cleaning, &c.		705 6 2
,, Library Books and Binding		76 16 3
,, Library Catalogue		58 12 6
,, Office Furniture		81 9 5
,, Autumn Meeting		74 11 8
,, Annual Meeting		67 15 2
,, Journal Publishing Expenses :—		
Printing, &c.	£1,018 7 3	
Abstracts	123 19 2	
Translations	51 16 1	
Postages	106 9 10	
		1,300 12 4
,, Stationery and Printing (including copies of Papers)		278 14 9
,, Postage and Receipt Stamps		93 14 3
,, Insurance		6 18 10
,, Bessemer Medal Fund Expenditure :—		
Gold Medal		15 5 0
,, Telephone		18 10 0
,, Travelling Expenses		19 6 8
,, Auditor's Fee		21 0 0
,, Sundry Payments		40 11 8
,, Carnegie Scholarship Fund :—		
Scholarships	£850 0 0	
Medal	15 5 0	
Printing Research Memoirs	249 11 3	
Postage of do.	31 6 6	
Translations	50 11 9	
Advertising	3 4 2	
Salaries	52 9 0	
Postage (General)	1 11 10	
	£1,253 19 6	
Less Balance of Scholarships for 1910 and 1911 lapsed	150 0 0	
		1,103 19 6
,, Balance, being excess of Income over Expenditure :—		
General Account	£608 4 8	
Less Deficit on Carnegie Scholarship Fund	103 12 9	
		504 11 11
		£6,310 8 0

BALANCE-SHEET, DECEMBER 31, 1914.

LIABILITIES.

To Sundry Creditors :—		
Journal Printing and Publishing	£352 0 11	
Journal Postages	47 5 3	
Library Books and Binding	14 9 7	
Library Catalogue	58 12 6	
Office Rent, &c.	179 18 2	
Printing and Stationery	51 4 11	
Sundry Payments	4 3 2	
Autumn Meeting	3 13 8	
On account of the International Congress of Mining and Metallurgy, London, 1915	1 18 2	
Carnegie Scholarship Fund :—		
Scholarships due, 1914	425 0 0	
Do. do. 1913	25 0 0	
Printing of Memoirs	249 11 3	
Postage of do.	31 6 6	
		£1,444 4 1
,, Subscriptions in advance		48 6 0
,, Carnegie Scholarship Fund :—		
Amount at Credit thereof at 1st January 1914	£429 13 8	
Less Excess of Expenditure over Income for the year	103 12 9	
		326 0 11
,, The Iron and Steel Institute Capital Account :—		
Amount at Credit thereof at 1st January 1914	£1,277 3 0	
Add Excess of Income over Expenditure for Year	608 4 8	
		1,885 7 8
		£3,703 18 8

ASSETS.

By Subscriptions in arrear, since received			£58 16 0
,, Entrance Fees in Arrear, since received			21 0 0
,, Interest on Investments accrued, due at 31st December 1914, since received			261 14 11
,, Journal Sales, since received			104 19 9
,, Investments on account of Life Compositions :—			
North-Eastern Railway 3 per cent. Debenture Stock, cost		£1,254 17 6	
London Electric Railway 4 per cent. Perpetual Debenture Stock, cost		304 14 11	
Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock, cost		383 11 2	
North British Railway 4½ per cent. 1875 Irredeemable Preference Stock, cost		371 13 9	
			2,264 17 4
,, Expenses of International Congress of Mining and Metallurgy, 1915, since received			1 4 7
,, Expenses of International Testing Association, since received			20 14 7
,, Telephone Deposit			1 0 0
,, Cash at Bankers and in Hand :—			
On Deposit Account		£300 0 0	
On Current Account	£483 19 11		
Less Account Carnegie Fund	1 17 6		
		482 2 5	
Secretary's Balance :—			
At Bank		141 6 9	
In Hand		0 2 3	
			923 11 5
,, Carnegie Scholarship Fund :—			
Interest on Investments accrued, due at 31st December 1914, since received			46 0 1
			£3,703 18 8

INVESTED FUNDS OF THE INSTITUTE.

	£	s.	d.
£3744 North-Eastern Railway 4 per cent. Preference Stock, cost	£4,297	6	7
£788 North-Eastern Railway 4 per cent. Guaranteed Stock, cost	1,008	14	0
£79 4s. 5d., "B" Annuity, Scinde, Punjaub, and Delhi Railway, expiring 1958, with a Sinking Fund to replace the amount of Stock, cost	1,999	0	7
£50 1s. 8d., "B" Annuity, Great Indian Peninsula Railway, expiring 1948, with a Sinking Fund to replace the amount of Stock, cost	1,267	6	0
£1500 Buenos Ayres Great Southern Railway 4 per cent. Debenture Stock, cost	1,594	12	9
£1000 Commissioners for the Port of Calcutta 4 per cent. Bonds, 1939, cost	982	10	0
£800 Trustees of the Port of Bombay 4 per cent. Bonds, 1939, cost	809	0	0
£750 Great Central Railway 3½ per cent. Second Debenture Stock, cost	659	12	6
£750 Great Northern Railway (Leeds, Bradford, and Halifax) 6 per cent. Guaranteed Stock, cost	1,140	8	6
£511 South-Eastern Railway 3½ per cent. Perpetual Debenture Stock, cost	449	4	5
	£14,207	15	4

INVESTMENTS ON ACCOUNT OF LIFE COMPOSITIONS.

	£	s.	d.
£1330 North-Eastern Railway Irredeemable 3 per cent. Debenture Stock, cost	£1,254	17	6
£335 London Electric Railway 4 per cent. Perpetual Debenture Stock, cost	304	14	11
£335 Metropolitan District Railway 4 per cent. Prior Lien Debenture Stock, cost	333	11	2
£335 North British Railway 4½ per cent. 1875 Irredeemable Preference Stock, cost	371	13	9
	£2,264	17	4

ANDREW CARNEGIE RESEARCH SCHOLARSHIP FUND.

		£	s.	d.
$64,000	Pittsburg, Bessemer, and Lake Erie Railroad 5 per cent. Gold Debenture Bonds.			
$25,000	United States Steel Corporation 5 per cent. Gold Debenture Bonds.			
$11,000	Represented by:—			
	£2250 Newcastle-upon-Tyne Electric Supply 4½ per cent. Consolidated First Mortgage Debenture Stock, purchased at a cost of	£2,261	10	0
	Cash Balance uninvested	£1	17	6
$100,000				

(Signed) Wm. BEARDMORE, *Hon. Treasurer.*
G. C. LLOYD, *Secretary.*

I have examined the above Balance Sheet and accompanying Income and Expenditure Account with the Books and Vouchers of the Institute, and certify them to be correct. I have also verified the Balance at the Bankers and the Securities for the Invested Funds as shown above.

(Signed) W. B. KEEN,
Chartered Accountant.

23 Queen Victoria Street, London, E.C., *April* 23, 1915.

BESSEMER MEDAL FUND.

£534 London and North-Western Railway 3 per cent. Debenture Stock.

give the members any satisfaction, he would ask Mr. Lloyd to read the solicitors' letter.

The **Secretary** read the following letter:—

46 Parliament Street, Westminster, S.W.,
22nd April 1915.

Dear Sir,—We are in receipt of your letter of the 20th inst., and have perused the Bye-laws of the Institute. It is quite clear from these Bye-laws that there is no machinery for the removal of any member, honorary or otherwise, and we think the Council would do well to consider the advisability of amending the Bye-laws by empowering either the Council or the Institute to remove a member. With regard to the immediate question, it is clear that so long as we are in a state of war an enemy member resident in the enemy country could have no right of action against the Institute. The position of things would, of course, be altered after the end of the war, but even then it would be most difficult to estimate the damages to which the member had been subjected, and we think that the risk involved by the Council in taking the course indicated—(the course indicated was the removal of those members' names)—is so small that it may be practically ignored. Any amendment of the Bye-laws would, of course, have to be carried out under the provisions of Bye-law 20, and notice would have to be given to all members, including, we think, the enemy members.

Yours faithfully,

(*Signed*) Bircham & Co.

Mr. **Cooper** said that that was the position at present. As he had already stated, the question had been under consideration at the Council Meeting held that morning, and it had been decided to defer the matter to another meeting, when they would be able to give more consideration to it.

Mr. **Mure Ritchie** thought the members were exceedingly indebted to the Chairman and to the Council for having taken the preliminary steps for the inevitable action which must follow. At the same time he did not think the members could be content to let the matter remain where it was, and he thought the members were entitled to a distinct pronouncement from the Council that they intended to take up the matter and deal with it with the least possible delay. He had had a solicitor's training himself, and placed due weight on any legal opinion that was given, though he did not entirely agree with it. He thought it was quite certain the Institute had disciplinary powers over its own members. At any rate, even supposing the technical difficulty that had been raised existed, these were not the days, to use the Prime Minister's phrase, when juridical niceties should be allowed to stand in the way of doing that which was clean and honourable. He thought it would satisfy those who sympathised with the views which he held very strongly, and which he had no doubt were held quite as strongly on the Council's side of the table, if the Chairman would give the members an assurance that the matter would be dealt with before the present session expired; and that if it were necessary, in order to comply with any legal or technical formalities, a special meeting of the Institute should be summoned in order to alter the Bye-laws, so that immediately on the alteration of the Bye-laws the members might proceed to the expulsion of members of German and Austrian nationality or citizenship. He thought that would be perfectly satisfactory.

Mr. B. TALBOT (Cargo Fleet) desired to endorse everything Mr. Ritchie had said. There were many matters which the Council should deal with, but in the present case it was a matter which most of the members were called upon to decide. The members delegated many powers to the Council, but, speaking as an individual, the present was not one that he would delegate to anybody.

Mr. COOPER said he would presume that Mr. Ritchie would be content to leave the matter in the hands of the Council, with the assurance that the Council would do everything that they possibly could to carry out the wishes of the members. He did not think he could say more than that on the present occasion; the members now understood the position just as well as the Council did. He gave the members his word that the matter should be brought forward at the Council Meeting next month.

Mr. **Mure Ritchie** thought that was not a satisfactory proceeding. He thought the matter should be dealt with now; it was not one that brooked any delay. It was a matter that touched the honour of the members, and instant action was the only thing which would satisfy them. He was perfectly sure that instant and drastic action was the only method which would enable their great Institute to maintain its position in the eyes of the country. Whatever technical difficulties might exist, he was perfectly certain they admitted of quick and easy solution. Rule 18 said: "The Council shall convene a General Meeting for a special purpose upon a requisition to that effect signed by not less than twenty members." If necessary he should ask twenty members to sign a requisition at once in order that a Special Meeting might be convened, and in order that they might, at once, have the Rules altered so as to bring about that action which he was perfectly sure would commend itself to the great majority of the members of the Institute.

The **Secretary** said that Bye-law 18 did not specify the length of notice which it was necessary to give for that Special Meeting, but it would certainly be necessary to issue notices to the whole of the Institute in order to call such a General Meeting. The requisition could be signed at once if the members wished, and it would have to state the object for which the Meeting was called, and that would constitute the nature of the business to be discussed at the Special Meeting.

Mr. **Walter Dixon** (Glasgow) asked if there were any objection to the members present expressing their opinion there and then that it was their wish that the names of the German members of the Institute should be removed from the list.

Mr. **A. D. Ellis** (Bradford) appealed to the members, after the very definite statement that had been made by the Chairman, to leave the matter in the hands of the Council. By all means it should go out to the world that the Institute wished action to be taken; but in the meantime he thought, after the very definite statement Mr. Cooper had made, the members would be perfectly safe in leaving it in the hands of the Council, and he did not think for a moment that the Council themselves wished to defer taking steps.

Professor T. TURNER (Birmingham) supported Mr. Ellis's view that the matter should be left to the Council. He thought it would be very unwise for the members at the Meeting to take action at a moment like the present, when feeling was so strong. He thought that any action taken should be such that the Institute would not regret it ten or twenty years hence. He thought, therefore, it would be wise to leave the matter to the Council to see that the proper course was adopted.

Mr. W. F. BEARDSHAW (Sheffield) said that, as a member of more than twenty-five years' standing, he wished to ask Mr. Mure Ritchie to defer his proposition until a Meeting of the Council. There were over 2000 members of the Institute, and there were not more than 200 members present that day. He thought the Council would represent the opinions of the members much better than the individual members present. He strongly suggested that the Council should be supported and be asked to consider the matter carefully and report further.

Mr. COOPER asked whether it would meet the views of Mr. Ritchie and the gentlemen who were supporting him if the proceedings ended rather earlier that morning and a Special Meeting of the Council were held to consider the question further.

Mr. RITCHIE said that would certainly suit his views. He wished to say that he had had no consultation with anyone, nor had he spoken to anyone on the subject prior to entering the room.

Mr. **ILLTYD WILLIAMS**, Vice-President, suggested that Mr. Mure Ritchie should ask whether twenty members would stand in their places to support his proposed action.

Mr. **RITCHIE** did so, and considerably more than twenty members having risen from their places,

Mr. **COOPER** said there were far more than the necessary number, and he was not sure but that everybody present supported Mr. Ritchie.

Mr. W. P. **RYLANDS**, Member of Council, said the Report was drafted and adopted by the Council a month or six weeks before, and in the interval many things had happened. If it were possible he would like to propose that the words on the second page, "It has been decided to take no active steps for the removal of their names from the List of Members," be deleted.

Mr. W. H. **ELLIS**, Vice-President, seconded the motion, which was carried unanimously.

On the motion of the Chair, the Statement of Accounts was then adopted.

PRESENTATION OF BESSEMER MEDAL.

Mr. **COOPER** said that in the absence of the honoured President, Dr. Greiner, the very pleasant duty devolved upon him of presenting the Bessemer Gold Medal for 1915, which had been awarded by the Council to Mr. Pierre Martin,[1] the inventor of the Martin process, or, as it was commonly called in this country, the open-hearth process, for the manufacture of steel. Mr. Martin's first patent was taken out in July 1865, and, as was well known, consisted of melting a mixture of pig iron with steel scrap or with oxide of iron or with both. The actual discovery that steel could be made in that way was not new. Many metallurgists before Martin's time had demonstrated the possibility of the method, but all their efforts to carry the results into practical effect had failed, mainly for the reason that they lacked the means of maintaining continuously a sufficiently high temperature in the hearth. In 1861 a great step in advance was made when Sir William Siemens invented the regenerative furnace, by means of which the difficulty of temperature was overcome. Pierre Martin carried out his experiments in a Siemens furnace of 1 ton capacity, and after many disappointments and trials he at length succeeded in applying the process to steel-making on an industrial scale. At the Paris Exhibition of 1867 Mr. Martin showed a number of commercial products obtained by his process, for which he was awarded the Gold Medal at the Exhibition, and the process was shortly afterwards adopted at several French steelworks. The invention of Pierre Martin was incontestably a most important one, in that he obtained a class of steel of regular quality and composition by a new method. He had, however, attained his end by the use of a combination of appliances and processes most of which were already known. It could be no matter for surprise, therefore, that immediately the success of Martin seemed assured, the validity of his patent was attacked on all sides. Costly lawsuits followed which he unfortunately had not the means successfully to defend, and he was eventually compelled to abandon the struggle and retire into private life, without reaping the just reward of his industry and perseverance, although it had never been denied that the merit of the practical solution of the problem belonged to him alone. The obstacle to the extensive adoption of the Martin process in its early days was that by the time the invention had reached the practical stage, the Bessemer process already occupied the field, and on account of the greater cost of the Martin process, it was unable for many years to make headway against its powerful rival. But the excellence of the product told, and the Martin process gradually won its way. The introduction of the basic process by Thomas and Gilchrist in 1879 enormously increased its application, until to-day it had far outdistanced the Bessemer in quantity of production. In 1913 upwards of 44,000,000 tons of acid and basic steel were produced by the Martin process, whilst the production of the Bessemer process scarcely reached 30,000,000 tons. Those facts alone afforded to the world some indication of the vast importance of the invention with which Mr. Martin's name was honourably associated. Mr. Martin's state of health unfortunately prevented his being present and welcomed at the Meeting on the present occasion, and His Excellency the French Ambassador had graciously consented to receive the medal on behalf of his compatriot. Unfortunately, however, urgent duties had required the Ambassador's presence elsewhere, and at his request Mr. de Fleuriau, Counsellor of the French Embassy, had been kind enough to attend as his representative, a compliment of which the Institute was deeply sensible. Mr. de Fleuriau was accompanied by Captain Paul Zédé, one of the officers attached to the Embassy, to whom the Institute also extended a cordial welcome as the nephew of Mr. Pierre Martin, to whom it was the Institute's privilege to do honour that day.

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[1] The Secretary deeply regrets having to record the death of the recipient a few days later. An obituary notice of Mr. Pierre Martin will be found in the present volume.

In presenting the Bessemer Medal to Mr. de Fleuriau, Mr. Cooper trusted he would be pleased to receive on behalf of his distinguished fellow-countryman, Mr. Pierre Martin, the highest honour which it was in the power of the Iron and Steel Institute to confer.

Mr. de Fleuriau, in accepting the medal, thanked the Institute very much for their kindness in presenting it, and said he would convey it to Mr. Martin. All he could say was that he happened to know in his official capacity that most of the shot fired now by the French against the enemy was made of steel which was manufactured in Great Britain.

Captain Paul Zédé said he was very sensible of the great honour that had been done to his family. His uncle, Pierre Martin, was a man of a retiring character, and unaccustomed to the meetings of great societies such as the Iron and Steel Institute, but he certainly would have had great pleasure had he been able to come himself on the present occasion. On behalf of his uncle, he thanked the members very much, and would transmit to him an account of the very kind things which had been said and the very kind way in which he himself had been received.

The following telegram was read from Mr. Pinot:—

> "The Comité des Forges de France desire to unite and express their sincere good wishes to President Greiner, and also their cordial thanks at the honour done to Mr. Pierre Martin, and they hereby transmit to their allies, the British Iron Masters, their expression of their greatest confidence in victory."

A letter was also read from Sir **HUGH BELL**, expressing regret at the absence of the President, and tendering his sympathy.

A Note contributed by the President, Mr. **ADOLPHE GREINER**, D.Sc., on the "Heating of Open-hearth Furnaces by Means of Tar," was then read by the Secretary.

The **CHAIRMAN** said the Council had decided to regard the communication as an addendum to Dr. Greiner's Address of last year, and therefore it was proposed that it should not be discussed, but he was sure the members would all agree with him in passing a very cordial vote of thanks to Dr. Greiner, particularly having regard to the conditions under which the Note had been written. He would also like to go further and move: "That the members of the Iron and Steel Institute assembled in General Meeting hereby desire to convey to their honoured President, Dr. Adolphe Greiner, the expression of their high appreciation of his great services to the Institute and their best wishes for his continued good health and activities in his present sphere of work."

Professor **ANDREW McWILLIAM** (India), in seconding the motion, hoped the members of the Institute would stand in passing it.

The motion was carried unanimously by the members rising.

A paper by Sir **Robert Hadfield**, F.R.S., Past-President, and Dr. **George K. Burgess**, Bureau of Standards, Washington, on "Sound Steel Ingots and Rails," was then read and discussed, and the meeting was adjourned to the following morning.

Mr. **Arthur Cooper**, in opening the adjourned meeting at 10 A.M. on the morning of Friday, May 14, said that attention had been called at the meeting held the previous morning to the paragraph in the Report of Council having reference to alien enemy members. It was explained that the paragraph was drafted two months ago; that the Council had realised that a great deal had happened since then; that it had had the question under consideration at the Council Meeting held that morning, and had decided to defer further consideration of the subject until the next Council Meeting, when more time and thought could be given to it. Having regard, however, to the strong expression of opinion of the members present at the previous morning's meeting, another Council Meeting had been held at half-past twelve, and the Council then decided to amend the Report, so that it would now read:

"The Council have under consideration the position of these Members."

Further, the Council adopted the following resolution:

"That the names of all alien enemies be struck off the List of Members of the Institute, and that steps be taken to amend the Bye-laws so that they provide for the future that, in the event of war existing between this and other countries, citizens or subjects of which are Honorary Members or Members of this Institute, such Honorary Members or Members shall *ipso facto* cease their membership."

As Mr. Ritchie had been the spokesman of the members at the previous day's meeting, he (Mr. Cooper) would be glad to hear whether that resolution would be satisfactory to him, and whether it would be adopted by the members.

Mr. **Mure Ritchie** said he had had no opportunity of discussing the matter with more than two or three of his fellow-members, and he could therefore only speak for himself. With that limitation, he desired to say, without any hesitation, that the proposed resolution seemed to him to meet the case at the moment. He desired also to say, in the first place, that, personally, he had no prejudice whatever against enemies of non-German nationality or origin, and still less had he any against the Hungarians, between whom and this country there were many old and strong ties of friendship. He hoped and believed the time would come when members of the Institute who belonged to those nationalities to which he had referred would again be welcomed at the Institute, but he suggested that German subjects of the German Empire were in an entirely different category. They had put themselves completely outside the pale of civilisation; they had descended to depths of savagery such as no human being could have contemplated a few months before; in fact, he was quite sure there was not a single person present on either side of the table who would not agree with him when he said that it would be simply impossible to find language adequate to describe the attitude and condition of Germany. He therefore suggested that, when the time came for the Council to consider the question of amending the Bye-laws, some specific notice should be taken of the case of Germans.

Mr. COOPER then moved from the Chair: "That the Report of the Council as amended be adopted."

Mr. MURE RITCHIE said he had very much pleasure in seconding that motion, always provided it was on the conditions he had indicated.

The Report having been adopted, Mr. COOPER said the Secretary had received instructions from the Council to see the Institute's solicitors for the purpose of making any alteration of the Bye-laws that might be necessary to carry out the resolution he had read. He presumed the resolution the Council had adopted in reference to the striking off of the names of all alien enemies was accepted by the members. He asked those who were in favour of it to signify the same in the usual manner.

The resolution was then put from the Chair and carried unanimously.

Presentation of the Carnegie Gold Medal.

The Chairman announced that the next business on the Agenda was the presentation of the Carnegie Gold Medal to Mr. Eugene Nusbaumer of Paris. He was sorry to say that Mr. Nusbaumer could not be present at the meeting, but Professor Le Chatelier had very kindly consented to accept the medal on his behalf.

It was his pleasing duty to announce that, by the unanimous vote of the Council, the Carnegie Gold Medal for the year 1914 had been awarded to Mr. Eugene Nusbaumer of Paris. Mr. Nusbaumer was educated at the University of Paris, and at the Institute of Applied Chemistry in the same city. Afterwards he was appointed chief chemist at the works of Messrs. G. Derihon, at Loncin-lez-Liége, Belgium. During the time that he held that position he carried out an important series of investigations on the wear of metals, and on alternating stresses, the results of which were contributed, in 1909, in the form of a memoir to the Copenhagen Congress of the International Testing Association. In 1912 the Council of the Iron and Steel Institute awarded him a Carnegie Research Scholarship, to enable him to carry out experiments in connection with the testing of materials, the results of which he presented to the Institute in the previous year in the form of a report entitled "Rotary Bend Tests, Alternating Bend Tests, and Repeated Shock Tests." After spending several months in the United States, for the purpose of improving his practical experience, Mr. Nusbaumer returned to France in August 1914, and now held a commission in an artillery regiment. His duties at the present moment had unfortunately prevented his attendance at the present meeting, to receive the medal in person.

It afforded him, on behalf of the Council, very great pleasure to hand the medal to Prof. Le Chatelier for presentation to Mr. Nusbaumer.

The **Chairman** then presented the medal to Prof. Le Chatelier.

Prof. **Le Chatelier**, speaking in French, thanked the Institute on behalf of Mr. Nusbaumer, who was sorry he had been unable to come to the meeting. Like all Frenchmen, he had been mobilised, and at the present time he was at the front in a regiment of artillery. He would feel much honoured by the distinction which had been conferred upon him; it would encourage him to continue his studies in the same direction.

AWARDS OF CARNEGIE SCHOLARSHIPS.

The **Secretary** announced that awards of Carnegie Scholarships of the value of £100 each had been made by the Council to the following:—

E. L. **Dupuy**, Paris.
J. A. N. **Friend** (second award), Worcester, England.
W. D. **Helderman**, Utrecht.
T. G. **Thompson**, Seattle, Washington, U.S.A.

Further grants of the value of £50 each had been made to:—

H. M. **Boylston**, Cambridge, U.S.A.
H. B. **Cronshaw**, Cambridge, England.

who were awarded Scholarships of £100 in 1914.

The following are brief notes of the careers of the successful candidates and Scholars above mentioned:—

ANDREW CARNEGIE GOLD MEDAL.

E. **Nusbaumer**, of Paris, of whose earlier career particulars are given in the *Journal of the Iron and Steel Institute*, 1912, No. I., on the occasion of his receiving an award of £100, is now awarded the Carnegie Gold Medal in recognition of the merit of his researches on "Rotary Bend Tests," the results of which were published in Volume VI. of the *Carnegie Scholarship Memoirs*.

ANDREW CARNEGIE SCHOLARSHIP AWARDS FOR 1915.

Eugene Louis Dupuy, of Versailles, was born in 1888, and was educated at Paris and at Rome. He spent two years (1908–1910) at the Faculté des Sciences de Paris (Sorbonne), where he received the degrees of Bachelor in Languages, Science, and Mathematics. During 1909–1910 he obtained Diplomas in General and Applied Chemistry and in Physics, and in the latter year obtained the degree of Licentiate in Physical Science. In 1914 he was awarded a premium of the University of Paris for researches on "Magnetic Properties of Alloys," and for the last six years had been making investigations in the Laboratories of Professor Nicloux, of the Museum, and of Professor Le Chatelier, of the Sorbonne. Since 1911 he has also acted as joint-editor of the *Revue de Métallurgie*. The nature of the proposed research for which he has been awarded a grant of £100 is the "Influence of Impurities in Steel on the Magnetic Susceptibility."

Dr. J. **Newton Friend**, of Worcester, particulars of whose career are given in the *Journal of the Iron and Steel Institute*, 1907, No. I., has been awarded a second Scholarship of £100 to enable him to pursue his investigations on the "Relative Corrodibilities of Iron and Steel"—a series of field tests. He received his first award of £100 in 1907, and further grants of £50 each in 1910 and 1911.

Willem Dirk Helderman, of Utrecht, Holland, was born in 1889. From 1908 to 1914 he studied at the University of Utrecht. He has devoted special attention to the study of the chemical properties of non-ferrous metals, and from time to time has published in the *Proceedings of the Royal Academy of Science of Amsterdam* the results of his research work on the "Allotropy of Zinc, Lead, Cadmium, and Copper." A Scholarship of £100 has been granted to him to enable him to carry out research work upon the "Metastability of Metals."

Thomas Gordon Thompson, of Seattle, Washington, was born in 1888. From 1906 to 1911 he was Assistant Chemist and Research Assistant in the Chemical Laboratories of the American Brass Company of Torrington, Connecticut, and Waterbury, Connecticut. During that period he made a study of iron, carbon, and alloy steel and non-ferrous alloys, coal, cement, and oil. In 1912 he was appointed Assistant Chemist to the American Steel and Wire Company, Worcester, Mass., where he studied carbon and alloy steels. From 1911 to 1914 he attended Clark College, Worcester, Mass., and obtained his A.B. degree. In September 1914 he was appointed Teaching Fellow of the University of Washington. He has been awarded a Scholarship of £100 for the purpose of carrying out researches on the "Protection of Iron and Steel from Corrosion."

Papers by Dr. A. McWilliam and Mr. E. J. Barnes on "Brinell Hardness and Tenacity Factors of a Series of Heat-treated Special Steels"; by Dr. J. E. Stead on "Iron, Carbon, and Phosphorus"; and by Mr. Kotaro Honda on "The Nature of the A2 Transformation in Iron" (presented in abstract by Sir Robert Hadfield, in the absence of the author) were then read and discussed.

The CHAIRMAN expressed his regrets that, owing to the shortness of time, it would be impossible to deal with the remaining papers on the programme, which would therefore have to be taken as read and discussed by correspondence.

The CHAIRMAN said there remained one other duty to perform before the meeting closed. The Institute had been the guests of the Institution of Civil Engineers in their magnificent building, and the members would be lacking in their duty if they did not pass a very hearty vote of thanks to the Institution for their hospitality. He therefore begged to propose: "That the best thanks of the members be given to the President and Council of the Institution of Civil Engineers for their kindness in placing their rooms at the disposal of the Iron and Steel Institute for the purposes of this meeting." That resolution needed no seconder.

The motion was carried unanimously.

Mr. W. F. BEARDSHAW (Sheffield) said there was one other duty, and that was to give a hearty vote of thanks to the acting President for his conduct of the meetings. Dr. Cooper had had a particularly difficult task in acting in Mr. Greiner's absence. On the previous day it was brought home to the members that the Institute was an international scientific

Society, and he was afraid some members had been led away by their feelings to an extent that made it difficult for Dr. Cooper and the Council to reconcile the views of all concerned. It was, therefore, with peculiar pleasure that he had to ask the members to pass a hearty vote of thanks to Dr. Cooper for presiding over the meeting.

The motion was carried with acclamation.

The CHAIRMAN expressed his obligation to Mr. Beardshaw and the members for the very hearty vote of thanks that had been accorded to him. Notwithstanding the fact that he was now entering on the fourth year of apprenticeship to the Chair, he was conscious of many shortcomings. If he had, however, conducted the business to the satisfaction of the members he was more than gratified.

The meeting then terminated.

LECTURE BY PROFESSOR H. HUBERT

(LIÉGE UNIVERSITY).

On the afternoon of Thursday, 13th May 1915, a Lecture was delivered by Professor Hubert, at the Institution of Civil Engineers, on "The Recent Progress in the Design of Large Blast-furnace Gas-engines," Sir Robert Hadfield, F.R.S., Past-President, in the Chair.

Sir Robert, in introducing Professor Hubert to the members, said that anyone who at the present time visited this country from Belgium would be warmly received, but he thought the members present would extend an even warmer welcome than usual to the representative of their gallant Ally, Belgium, on the present occasion. They were all greatly obliged to Professor Hubert for the trouble he had taken in preparing his very valuable Lecture, which he would now ask him to deliver.

The text of this Lecture will be found on p. 409.

NOTE ON THE HEATING OF AN OPEN-HEARTH FURNACE BY MEANS OF TAR.

BY A. GREINER, D.SC. (PRESIDENT).

IN the month of May last year, when I presented to the members of the Institute a note on the bye-products of modern metallurgy and dwelt on their actual or prospective utilisation, I was far from foreseeing the unhappy circumstances—such as those from which we are all suffering at the present moment—which would compel the Cockerill Company to face the solution of a fresh problem of this nature. After the total stoppage of the works entailed by the foreign occupation, and once the preliminary period of disorganisation had passed, it appeared to us that we had a pressing duty before us — that of helping the working-class population around us to the utmost extent of our power to earn its livelihood. For this reason I decided at once to undertake the manufacture of a portion of the orders we carried on our books, so far as circumstances would allow.

The steelworks were thus compelled to contemplate the necessity of relighting an open-hearth furnace. Our reserves of gas coal had been speedily exhausted; the only battery of coke-ovens which was working was unable to furnish us with gas, of which it was itself in pressing need; the importation of British coal was impossible, and, as a matter of fact, we felt the need of freeing ourselves from the long established dependence of the works upon foreign countries as regards the supply of gas coal. There remained, as our sole resource, the tar from the coke-ovens.

I had quoted last year some figures relating to the use of this fuel at the Gary Works in the United States; that which others had succeeded in doing we likewise wished to do. Indeed, even as far back as last summer, experiments had been undertaken for heating by tar the little 12-ton furnace kept for our experiments, which had already been modified for the purpose of utilising coke-oven gas. With this furnace the members of the Institute are already familiar.[1] These earlier experiments were carried out by employing injectors of a very rough kind, which were led in, one at each end of the furnace, in the axis of the port of delivery of the coke-oven gas. An arrangement of this description allowed us, in the event of delay or stoppage, to have recourse, without loss of time, to the older form of fuel, which always remained available. Indeed, as a matter of fact, during this experimental period, I am compelled to admit that the inconveniences arising from the use of tar were numerous, and we only succeeded in finishing a few of the charges commenced with this fuel, without being compelled to fall back on the earlier method of heating. So much was this so, that when we found ourselves brought to a standstill for want of the coal which might have been used to feed some other furnace, the problem was a long way from having been solved.

Nevertheless, the stimulus of need, added to the satisfaction that we promised ourselves at being able to do without foreign coal, decided us to employ this mode of heating, by hook or by crook. It is not my intention to describe here the details of an installation so often modified, and still less the succession of set-backs which neither rebuffed nor discouraged the engineer, Mr. Bourgy, who was in charge of the open-hearth furnace. I will confine myself to saying that not a single charge was lost. On the contrary, experience, even when unhappy, being a fruitful lesson, we arrived by successive modifications at furnishing this experimental furnace with sufficiently reliable appliances which have enabled me to-day to put before you a few figures resulting from practice that has become truly commercial.

These results relate to a campaign of ten weeks' work, from January 10 to March 20, 1915, undertaken in the furnace after repairs, and during which, apart from the intervention of Sunday, the only stoppage of work resulted from a delay in the deliveries of fuel (a detail which it is not always possible to control). Owing to various circumstances, the furnace was stopped at the end of ten weeks after having produced, in 215 charges, a total of 1986 tons of steel of varying composition.

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[1] *Journal of the Iron and Steel Institute*, 1913, No. II. p. 93.

In the present arrangement the tar is delivered to the sprayers (one only in each burner) with a regular feed and under a uniform pressure of half an atmosphere. It is sprayed by means of air compressed at about three atmospheres. The hot air of combustion is admitted above the injector through the existing port, inclined at an angle of 45 degrees. The average consumption of tar throughout the whole campaign has been 133 kilogrammes (300 lbs.) per ton of steel, including in this figure the amounts required for lighting up and for heating during stoppages. On the other hand, with an uninterrupted run, this average falls to 115 kilogrammes (250 lbs.) per ton of steel. The average weight of the charges had to be diminished in order to avoid any deflection of the jet of flame issuing from the pulveriser towards the crown of the furnace. Nevertheless, several charges of 15 tons have been worked successfully without any other inconvenience than a proportionately longer working time.

The proportion of pig iron found necessary in the charge rose to 28 per cent.

I may add that, after these 215 charges, the furnace is still in an excellent working condition. The roof appears even less damaged than after a similar campaign with coke-oven gas; only the chambers became encrusted. The bricks of the checker work became covered with a carbonaceous substance, and it will be necessary to devise some means of remedying this inconvenience.

I wish to add that, as a sequel to the satisfactory results we are obtaining, we have built a new furnace of 25 tons capacity, furnished with appliances completely modified for the purpose of the exclusive utilisation of tar as a fuel. This new furnace has been in operation since the beginning of April, and I hope that before the publication of the Journal I shall be able to give the results of fresh experience relating to it.

The following table affords a comparison of the different results of experiments obtained with this same small 12-ton furnace when working, as originally, with producer-gas; with coke-oven gas (after a modification of the chambers and of the burners); and, finally, when using tar, and without any further modification than the addition of the pulverisers:

	Heated Producer-Gas + Hot Air.	Cold Coke-Oven Gas + Hot Air.	Tar + Hot Air.
Tonnage produced during campaign .	2624 T.	3516 T.	1986·5 T.
Average daily production . . .	39 T.	48 T.	38 T.
Average proportion of pig iron per charge	31 per cent.	21 per cent.	28 per cent.
Average waste	5·5 per cent.	4 per cent.	4·8 per cent.
Fuel consumption per ton of steel .	300 kgs. (650 lbs.)	280 cub. met.[1] (9800 cub. ft.)	115 kg. (250 lbs.)
Cost of heating per ton of steel[2] .	8·40 francs. (6s. 9d.)	4·20 francs. (3s. 4d.)	4·60 francs. (3s. 8d.)

The furnace and arrangements described have been at work since April 15, and ingots have been produced regularly up to 22 tons. The consumption of crude tar has averaged about 12·5 per cent., and no trouble whatever has been experienced either with the brick work or with the tuyere arrangement.

[1] This figure is difficult to determine accurately.

[2] This is based on the following:—

1 ton of gas coal, including cost of gasification, costs 28 francs (£1, 2s.).
1 cubic metre of coke-oven gas costs 1·5 centime (0·15d.).
1 ton of tar costs 40 francs (£1, 12s.).

SOUND STEEL INGOTS AND RAILS.

By Sir ROBERT A. HADFIELD, F.R.S. (London), and Dr. GEORGE K. BURGESS (Bureau of Standards, Washington).

1. Introduction.

The methods of production of sound steel ingots, of which a bibliography is given at the end of this paper, have been described in several papers read before this and other Institutes. It was thought by Director Stratton of the Bureau of Standards and the present authors to be of sufficient interest and importance, as a further contribution to this subject, to compare the properties of rails rolled in one mill, according to American practice, from several types of ingot of substantially the same chemical composition, but cast by several processes, and to compare in considerable detail the properties of a number of ingots manufactured by the special feeding process of one of the authors, and one ingot of the usual type for rolling into rails.

We are indebted to Mr. Wood, President of the Maryland Steel Company, who made this investigation possible by kindly placing this rail mill at our disposal. He and his associates at Sparrow's Point did their utmost to make the experiments successful, including the execution of many of the tests and analyses.

The English co-author of this paper takes this opportunity of offering most cordial thanks to the Hon. W. C. Redfield, the Secretary of Commerce in the present United States Executive. The Hon. W. C. Redfield has rendered great assistance in this research, including financial grants from the American Government to the Bureau of Standards, enabling them to carry out investigations of this kind. As his American colleague cannot very well do so, the English co-author thanks Dr. Stratton, Director of the Bureau of Standards, Washington, D.C., U.S.A., for the help he has so kindly rendered in this research.

The desire of the Hon. W. C. Redfield has been to aid this research in every possible way, with a view to bring about improvements in practice which would add to the safety of the American travelling public.

If more of such friendly assistance were shown by the official heads of Government Departments, not only in America but elsewhere, quicker and greater advances in the practical application of science and industry would be found to follow, with consequent advantage to the public generally.

It is true that on British railroads the dangers arising from broken and defective rails are not met with to the same extent as in America. In the latter country not only are the traffic conditions severe owing to the heavy freight cars used there, but the effects of climatic conditions on the railroad bed due to the extreme changes of temperature have to be met to a much greater extent than in Great Britain. Increased soundness of railroad material, whether for rails, axles, tyres, or other purposes, means, therefore, an improvement in products used for railroad service, with consequent greater safety and higher durability.

It should again be pointed out that the manufacture of rails from sound steel produced by the system described, whether as regards mild, medium, or hard steel, is only typical of one of many instances of its application with consequent saving of material and reduction of heavy waste or discard.

Without doubt a general application of the use of the system would result in the saving of many million tons of steel each year, besides obtaining better products.

The reason for selecting "rails" to illustrate the application of the system was that one of the authors had been investigating in America the character of certain types of ingots and rails. It was therefore thought that the present opportunity was a particularly suitable one to obtain a comparison between rails from somewhat imperfect ingots produced in the ordinary manner, as shown by Fig. 2, and from ingots in which the material dealt with was free from blowholes, piping, and segregation. It should be added that the ingot represented by Fig. 2 is probably one fairly typical of those produced for rail steel, not only in America but in this country and on the Continent.

As a proof of the serious nature of segregation effects, not long ago a steel came before one of the authors which in its normal condition contained 0·15 per cent. carbon, 0·012 per cent. sulphur, and 0·011 per cent. phosphorus. In other words, it was of excellent quality, yet owing to carelessness in the manufacture of the ingot, the top portion had segregated, causing the sulphur to reach no less than 0·078 per cent. Such an ingot when rolled into a plate or other product would probably at some time in its future career give rise to serious trouble.

In another contribution on this research by the authors of the present paper a comparison of the two kinds of ingots referred to was summed up as follows:—

Remarks collected from the summing-up by Dr. Burgess regarding the comparison of the Two Split Ingots shown by the Illustrations in Figs 1 *and* 2.

The ingot cast by the feeding method, after being split or sliced open vertically on the axis line, presents a perfectly smooth clear surface, altogether free from pipe, seams, blowholes, or other imperfections.

The ingot representing the average rail ingot, split open in the same manner, presented the usual piped appearance of such an ingot, no less than about one-half being unsound and unsuitable for rolling into rails.

The ordinary piped ingot is unsound and unsuitable for rolling into rails for over half its length, whereas the ingot cast by the feeding method is sound throughout the whole of its length.

Inspection indicates that a discard of 50 per cent. would be necessary for the ordinary ingot, but only about 10 per cent. in the case of the Hadfield ingot; that is, there would be practically no discard below the feeding head.

A sulphur print taken of one-half face of the Hadfield ingot indicates very uniform distribution of the constituents in the metal, and practically freedom from segregation.

As would be expected, the comparison ingot with its pronounced pipe shows marked segregation of carbon, phosphorus, and sulphur in the piped region to a depth of 25 per cent.

from the top of the ingot, and other regions of somewhat varying composition. The manganese shows but slight segregation anywhere.

This examination shows the overwhelming superiority of the ingots cast by the feeding process, such ingots being physically sound and uniform throughout, also free from segregation.

Drop tests on the rails from the Hadfield ingots show a high degree of uniformity of resistance to shock.

Uniform hardness is shown over the whole series of rails from the Hadfield ingots, whereas ordinary rails do not possess this quality.

The "A" rail from the Hadfield ingot is sound, beautifully so, right up to the front end or to the "bloom crop" itself. The ordinary ingot is unsound.

The web, which is usually the part consisting of the poorest material, is practically uniform in the case of the Hadfield ingots with the remainder of the section.

Examination of the rails shows that ingots cast by the Hadfield process will give rails of uniform quality, free from internal flaws of all kinds.

Dr. Burgess adds that in his opinion this research must prove of great value to the steel-maker, the railroad, and the public in America, England, and elsewhere.

2. CLASSIFICATION AND MANUFACTURE OF INGOTS.

Of the ingots used in this investigation there were eight made in Sheffield by the converter process, and furnished by one of us; also an ingot made and furnished by an American steel company,[1] as a comparison ingot, and supposed to represent the usual type of ingot from which rails are made.

The characteristics of the ingots are given in Table I. Ingots 1, 2, 3, and 4 were cast large end up, and fed by the Hadfield method in the usual manner with charcoal, the blast being continued until the molten steel has set on the top of the head, say, varying from 20 to 40 minutes. To ingots 1,

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[1] This ingot is not to be assigned to any particular manufacturer, as it is one of several from different sources, supplied, without special selection, as typical of the usual output of ingots.

TABLE I.—*Classification of Ingots.*

No.	Size, Inches.	Weight, Pounds.	Method of Casting.	Type of Steel.	Chemical Analysis.				
					Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
1	18	5,964	Hadfield system, large end up.	Ordinary rail steel.	0·59	0·21	0·041	0·031	0·97
2	18	6,006	Hadfield system, large end up.	Ordinary rail steel.	0·55	0·12	0·043	0·029	0·96
3	18	5,900	Hadfield system, large end up.	Nickel-chromium steel.	0·25	0·19	Ni 3·70	Cr 1·47	0·38
4	18	5,850	Hadfield system, large end up.	Ordinary rail steel.	0·56	0·19	S 0·040	P 0·035	0·92
6	18	5,200	Ordinary manner, small end up.	Ordinary rail steel which pipes, not fed.	0·56	0·20	0·060	0·051	0·94
7	18	5,100	Ordinary manner, small end up.	Ordinary rail steel of rising or boiling nature, not fed.	0·57	0·20	0·080	0·045	0·95
8	18	5,700	Hadfield system, small end up.	Ordinary rail steel.	0·58	0·23	0·070	0·051	0·96
9	18	5,700	Hadfield system, small end up.	Ordinary rail steel.	0·59	0·20	0·054	0·040	0·96
10	19	...	The American ingot, cast in ordinary manner, small end up.	Ordinary rail steel.	0·46	...	0·05	0·09	0·94

2, and 4 were added 0·1 per cent. of aluminium, and 0·125 per cent. was added to the nickel-chromium ingot No. 3. For the sake of comparison, there were also included two ingots, Nos. 8 and 9, cast with the small end up, and fed by the feeding method; three ingots not fed, two of piping steel, Nos. 6 and 10, and one of rising or "unsound" steel, No. 7. The Hadfield ingot No. 1 and the American comparison ingot No. 10 were cut up for examination as to segregation, blowholes, and piping, while the others were rolled into rails. It was expected that ingots 2, 3, and 4 would give rails of a uniform quality throughout nearly the whole length of the ingot, and that No. 1, which was selected by chance from the specially fed ingots cast large end up, would show a uniform, sound structure throughout. Previous experience has shown that ingots of the type of Nos. 8 and 9, cast by the Hadfield process with small end up, might be expected to be less satisfactory than the type represented by Nos. 2, 3, and 4 cast with large end up. The former sometimes show a tendency to develop a pipe. Ingot No. 6 might be expected to show piping and segregation, and No. 7 segregation and unsoundness; for both of these ingots a much greater waste might be expected than for special ingots Nos. 2, 3, and 4.

3. Examination of Split Ingots.

At the Pittsburgh Laboratory of the Bureau of Standards two of the ingots were sawn in halves—Hadfield No. 1 of the specially fed type cast large end up, and the comparison ingot No. 10 from an American mill. Figs. 1 and 2 are photographs of the two ingots, showing the location of drillings and a comparison of the interiors of the two ingots. The Hadfield ingot was also smoothed off in order to take a sulphur print, a reduced photograph of which is shown in Fig. 3. That there is an exceedingly uniform distribution of the constituents in ingots made by this improved method is evident. In Figs. 4, 5, and 6 respectively are shown the segregation of carbon, phosphorus, and sulphur for each of the ingots as determined in the chemical laboratories of the Bureau of Standards for seventy-nine positions between centre and edge. A similar survey was also made for manganese, no considerable segregation of this element being found in either ingot.

It is evident that there is freedom from appreciable segregation over 95 per cent. or more of the Hadfield ingot, which is also entirely free from piping or blowholes, and is sound throughout.

The comparison ingot, as would be usually expected with its pronounced pipe, shows marked segregation of carbon, phosphorus, and sulphur in the piped region to a depth of 25 per cent. from the top, and other regions of somewhat varying composition. This comparison ingot, if rolled into rails, should have about a 50 per cent. discard, as shown from the visual examination, while the whole of the Hadfield ingot below the feeding head would be available.

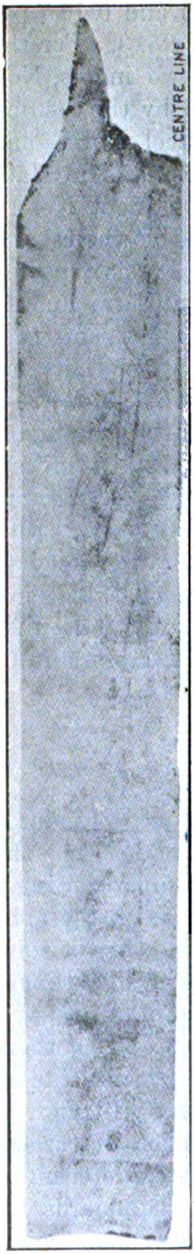

FIG. 3.—Photograph of Sulphur Print of Half Section of Hadfield Ingot.

It has been shown by Dr. Stead, Mr. Talbot, and others that an ingot of the ordinary type, such as the comparison ingot No. 10, may be somewhat improved as regards internal pipe by cogging while the centre is still fluid. This was referred to in the discussion on the paper by one of us.[1] Nevertheless, it is doubtful whether this treatment can be entirely relied upon, and in any case there are always evidences of segregation in the raw material.

It is also stated by rail manufacturers, with what correctness we do not know, that such an ingot (as No. 10), which is never allowed to become cold, may heal up in the interior during cogging, at least

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[1] "Method of Producing Sound Ingots," *Journal of the Iron and Steel Institute*, 1912, No. II.

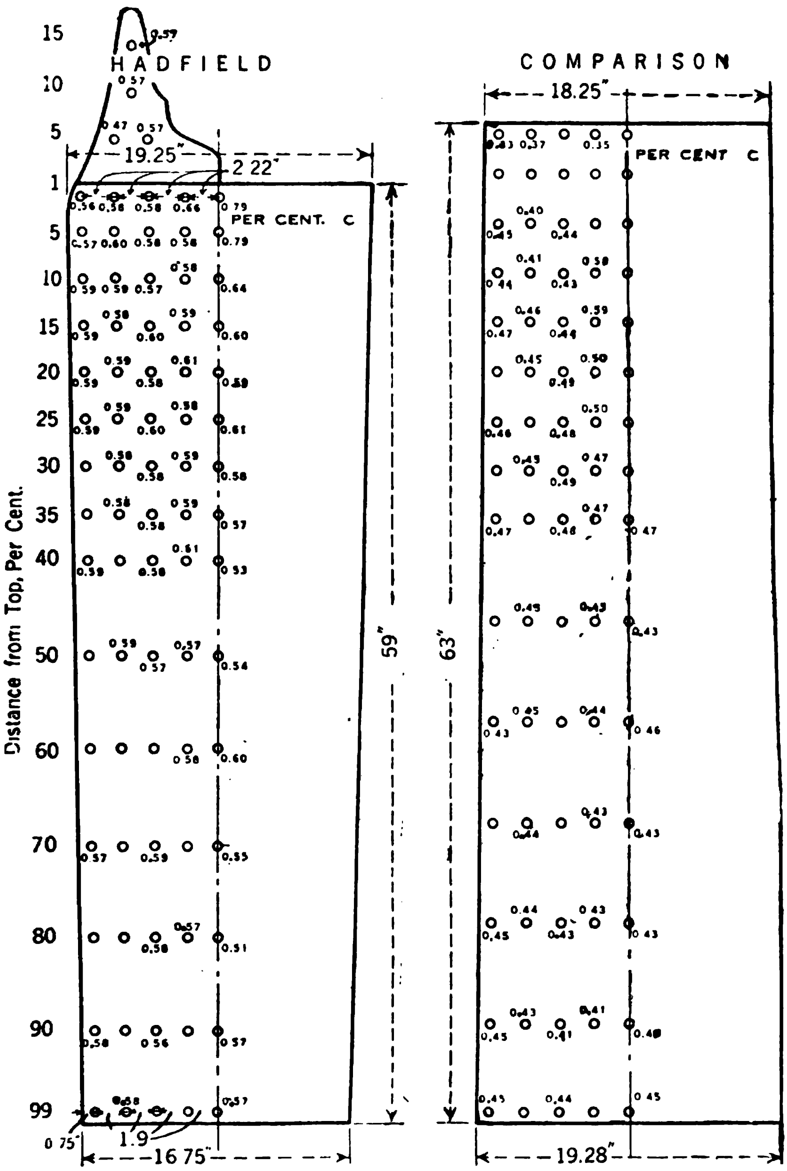

FIG. 4.—Carbon Segregation.

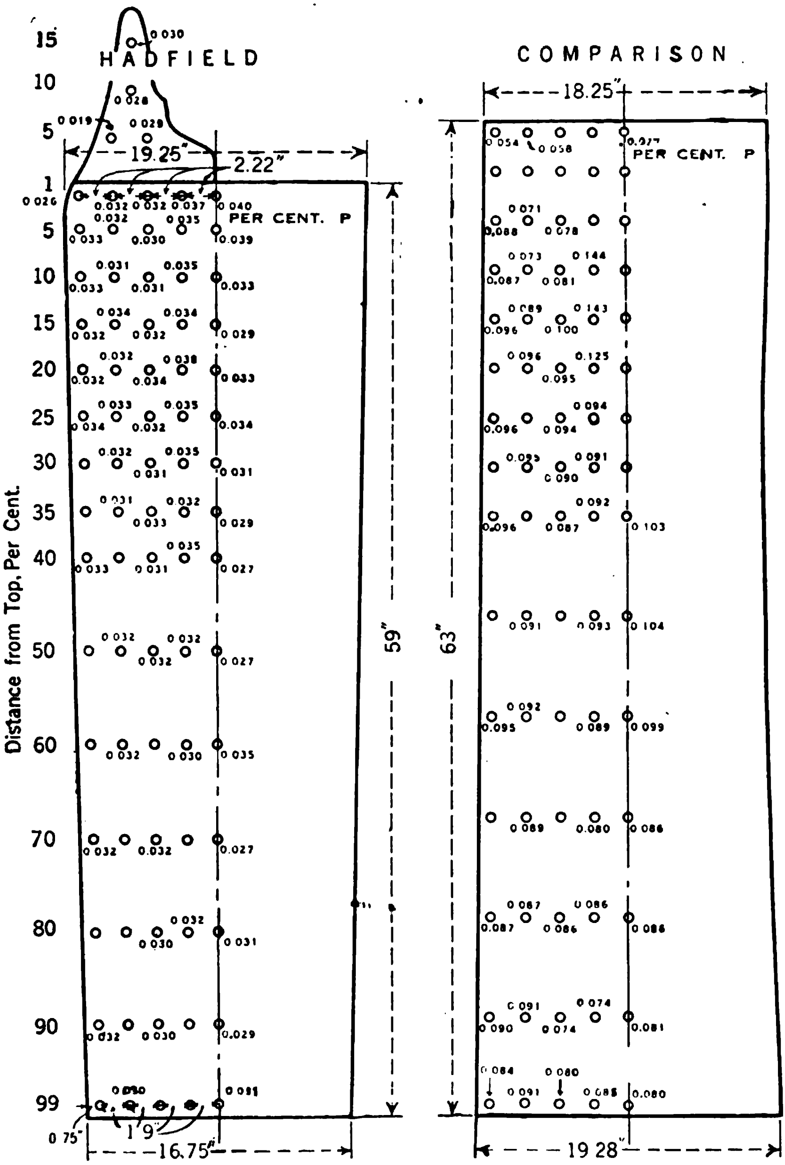

FIG. 5.—Phosphorus Segregation.

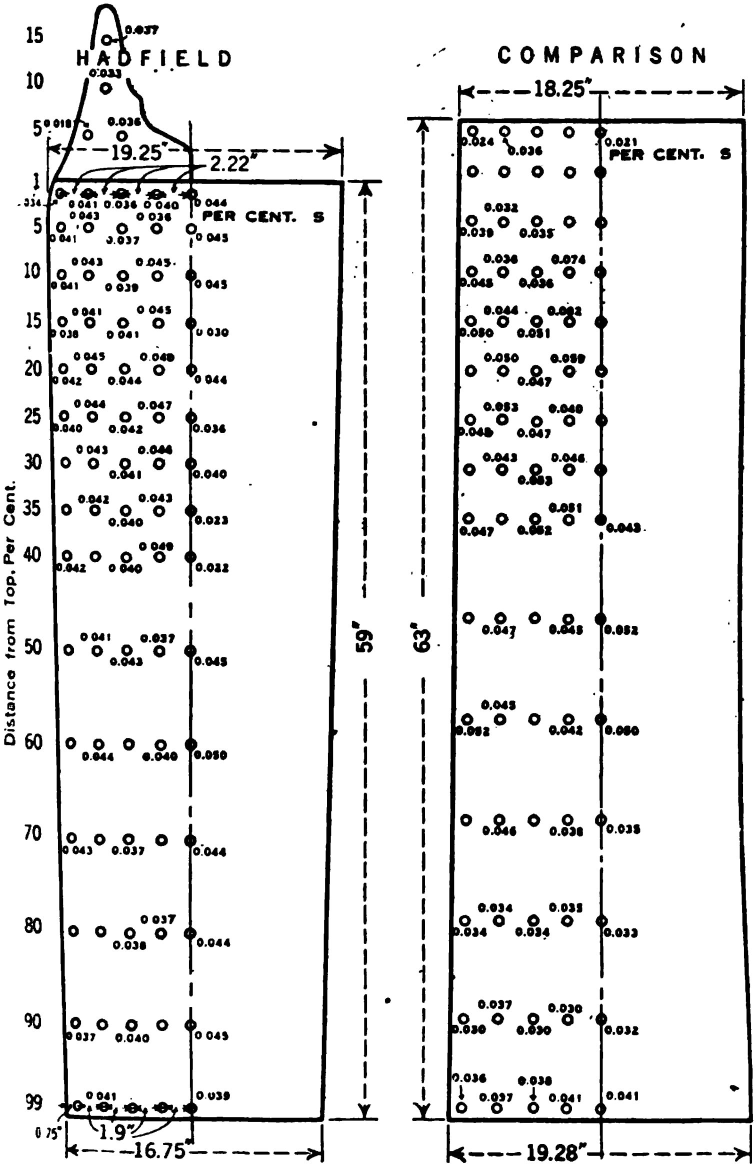

FIG. 6.—Sulphur Segregation.

partially, whereas an ingot allowed to become cold will not, in general, weld together. Probably in no case will perfectly sound material be obtained—that is, if the original ingot is unsound. It would also appear safe to say that any surface which has been exposed to the air will not weld satisfactorily.

As illustrative of the condition of the interior of ingots made by the ordinary processes we may cite the examination made on an extensive scale at the Watertown (U.S.A.) Arsenal;[1] the results obtained have been lately discussed by Mr. Wickhorst[2] and others. It would appear that our comparison ingot No. 10 is fairly representative of what may be expected in ordinary practice, showing that the so-called "healing" process is either very uncertain, limited, or does not take place at all.

Although an ordinary ingot (such as No. 10) may be undoubtedly improved over its condition as cast, nevertheless it would appear that considerable uncertainty always exists as to the actual final condition of such an ingot. The advantage of the special feeding process for ingots cast large end up consists in the certainty every time of producing an ingot free from pipe, blowholes, and marked segregation if sound piping steel has been used.

A very simple and easy inspection—one not in any way objectionable to the steel-maker—furnishes a definite check as to the condition of each ingot. For example, if there were not a proper sinking or falling down in the head, as shown at the top of the Hadfield ingot of Fig. 1, the ingot or ingots from the heat would not be passed.

That ingots cast by the Hadfield process, large end up, are always sound throughout has been demonstrated by cutting up and examining for flaws no less than 118 such ingots. These were not made specially but produced in the ordinary course of manufacture. Every one was found to be satisfactory. Since this experiment was carried out, many thousands of ingots made by the Hadfield system have been cut up, mostly transversely, but some longitudinally; not a single unsound ingot has been discovered.

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[1] *Tests of Metals, &c.*, Government Printing Office, 1909.

[2] *Bulletins of the American Railway Engineers' Association*, 1912–14.

It is, of course, evident that the securing of a completely solid ingot of uniform properties throughout its interior is in itself not sufficient to ensure the entire soundness of the resulting product, such as rails, rolled from such an ingot. For example, there are surface defects which may be present on the ingot; and the operations of reheating, blooming, and rolling may readily introduce serious imperfections. Nevertheless, in the Hadfield ingots the material is in the first case absolutely sound and free from blowholes. Therefore the liability to such imperfections is much less.

Not only are the qualities of the ingot improved, but these at once make themselves felt in the superior product obtained after rolling and forging. For example, when producing billets from ordinary ingots to be used for projectiles—that is, from ingots not cast by the sound method—it was found that there was no less than 6·2 per cent. of waster projectiles, owing to defects due to flaws and roaks, and arising from defects or unsoundness in the original ingots. In exactly the same class of article produced from ingots made from sound steel and properly fed by the method described in this paper, the total quantity of wasters reported was reduced to the figure of 1·4 per cent.; that is, wasters through seams, roaks, and other causes were reduced from 6·2 per cent. to 1·4 per cent., a reduction of no less than 4·8 per cent.

In a large daily output, it will be understood how great and important is the saving not only by avoiding the loss mentioned, but by also shortening the time of output.

Moreover, in America many failures have been found to result from defects known as "internal fissures," these being shown and fully described in the excellent paper "On Internal Transverse Cracks and Fissures in Rails" to the *Railway Gazette*, March 19, 1915, by Mr. Robert Job. It has also been stated by Mr. Wickhorst, Secretary of the American Railway Engineering Association, that these cracks or fissures, which are often of a really dangerous nature, were generally found to occur in the upper portion of what is usually known as the "A" rail, that is, from the uppermost portion of the rail rolled from the upper end of an ingot cast in the ordinary manner. It would, therefore, appear that if segregation and unsoundness can in the first place be eliminated from the ingot, as is the case with the ingots made under the system described in this paper, it is to be hoped that these dangerous internal fissures in rails can be decreased, and possibly made to altogether disappear, a point of great importance for American rail practice, in which the trouble now experienced in this respect is so considerable.

4. MANUFACTURE OF THE RAILS DESCRIBED IN THIS PAPER.

The ingots were charged into the soaking pits, which had been allowed to cool considerably, on Sunday evening, and rolled on Monday, April 13, 1914, at 8 A.M., into 100 lbs. P.S. section rails, the seven ingots being interpolated among other ingots, the mill working smoothly with no long waits. In the Maryland Mill the rolling from ingot to finished rail is a continuous process without reheating of the blooms. In Table II. are shown some of the characteristics of the rolling. Apparently through a misunderstanding of instructions and unfamiliarity with this type of ingot, the top bloom crops of the first two rolled specially fed Hadfield ingots, Nos. 2 and 3, were excessive—at least double what was necessary to carry the blooms through the rail mill. The other Hadfield and comparison ingots were sheared as instructed. Each ingot was sheared into two blooms, and each bloom furnished two rails of full length of 33 feet. The top or A rail was made the short rail—usually 6 to 10 feet long —to be examined as to soundness. The drop test specimen was cut next the bottom of this short A rail, a 13-inch specimen for tensile tests from the head of the C rail, and 3-inch pieces for chemical, metallographic, and hardness tests from the heads of the A, B, and C rails. Pieces were also cut to see if they had a bottom pipe from the bottom of the E rails of ingots 8 and 9, cast small end up by the Hadfield process.

Temperatures of the ingots in the blooming mill and of the rails at the hot-saw were taken by means of the Holborn-Kurlbaum type of Morse pyrometer as described elsewhere.[1]

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[1] Bureau of Standards Technologic Paper, No. 38, "Observations on Finishing Temperatures and Properties of Rails."

TABLE II.—*Rolling and Inspection of Ingots and Rails.*

Number of ingot	3	2	4	6	7	8	9
Taken from pit at	8 hr. 9 min.	8 hr. 40 min.	8 hr. 55 min.	9 hr. 11 min.	9 hr. 27 min.	9 hr. 43 min.	10 hr. 45 min.
Time in blooming mill	1 min. 40 sec.	1 min. 40 sec.	1 min. 42 sec.	1 min. 30 sec.	1 min. 40 sec.	1 min. 30 sec.	1 min. 40 sec.
Average temperature of ingot in blooming mill, deg. C.	1100°	1115°	1110°	1110°	1135°	1150°	1125°
Time blooming mill to hot saw	3 min. 50 sec.	4 min. 10 sec.	3 min. 23 sec.	4 min. 5 sec.	3 min. 20 sec.	3 min. 15 sec.	3 min. 22 sec.
Average temperature, first rail bar at hot saw	950°	960°	970°	970°	970°	980°	980°
Average temperature, second rail bar at hot saw	945°	900°[1]	950°	945°	955°	970°	965°
Top bloom butt, per cent. of ingot	4·2[2]	5·6[2]	7·8	12·9	5·0	5·1	6·3
Total bloom butts, per cent.	7·2	7·4	9·7	14·7	8·0	6·8	8·3
Oxidation loss, per cent.[4]	1·3	2·7	1·9	2·9	3·5	3·5	2·5
Percentage of ingot available for rails	91·5	89·9	88·4	82·4[3]	88·5	89·7	90·2
Rails—							
Percentage of firsts	77·2	77·1	52·5	9·5	54·3	51·9	28·5
Percentage of seconds[6]	22·8	22·9	47·5	90·5	27·4	48·1	23·8
Percentage of scrap[6]	0	0	0	0	18·3	0	47·7[5]
Type of ingot	Special feed, large end up.			Ordinary piping.	Ordinary rising.	Special feed, small end up.	

[1] Was held back before going to saw.
[2] Has been corrected as explained in section 4.
[3] Contains pipe, however, extending into C rail.
[4] It is to be kept in mind that all are reheated ingots.
[5] Two rails, C and D, from middle of ingot were scrapped for mechanical defects.
[6] This classification includes, of course, defects due to mill practice.

Table III.—*Brinell Hardness Numbers.*

Ingot.	Rail.	Hardness Number in Kilogrammes per Square Millimetre for Positions.								Mean.	Average Deviation.
		1	2	3	4	5	6	7	8		
2	A	250	253	250	251	272	258	258	251	255	±5·4
2	C	258	254	253	259	260	259	256	254	257	2·4
3	A	366	347	374	351	398	362	359	359	365	11·2
3	C	351	351	364	351	360	351	351	351	354	4·2
4	A	244	241	253	247	295	246	252	250	253	10·0
4	C	251	251	253	254	253	251	251	251	252	1·1
6	A	248	244	254	251	251	251	252	241	249	3·5
6	C	248	252	256	250	245	246	255	252	251	3·2
7	A	248	250	262	256	276	251	245	239	253	8·5
7	C	248	260	254	262	251	251	255	248	254	4·1
8	A	250	248	260	248	218[1]	258	260	254	250	8·5
8	C	254	258	264	251	279	261	263	263	262	5·6
9	A	248	251	251	245	236[1]	255	264	260	251	6·2
9	C	260	258	260	262	264[1]	264	264	263	262	1·9

[1] Seam or pipe through indentation.

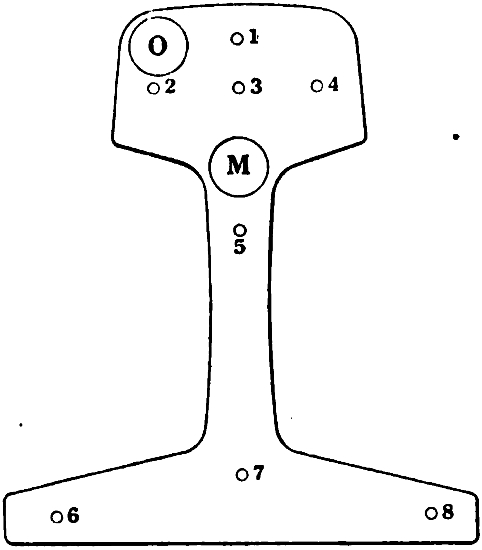

Fig. 7.—Rail Section.

O and M, positions of samples for chemical analysis.
1 to 8, positions of hardness tests.

The observations are the mean of several, usually four or five. As will be seen from Table II., the ingots were started on their course at substantially the same temperature, and the finishing temperatures are also uniform and about the average value for American practice.

Since the ingots were reheated from the cold state, the oxidation loss is perhaps somewhat more than would obtain in practice; this reheating from the completely cold state is also considered a more severe ordeal for the ingot than the usual practice. The rating of the rails as firsts, seconds, and scrap was done by the railroad inspectors who were examining the other rails being rolled; and, of course, includes all defects, whether originating in the ingot or in the mill practice.

It is to be noted that there are apparently available for rails from each of the ingots about 90 per cent. of the metal, with the exception of the piped ingot No. 6 (ordinary method of manufacture). The subsequent metallographic examination of the rails shows, however, that it is only the rails from the Hadfield specially fed ingots, cast large end up (Nos. 2, 3, 4), which can be absolutely relied upon to be sound to 90 per cent.

5. Tests of Rails.

(*a*) *Mechanical and Chemical.*—In Table III. are shown the Brinell hardness tests taken at the top of the A and C rails for positions shown in Fig. 7. It is of interest to note that, with the exception of rails with a pipe or seam (from ingots Nos. 6, 8, 9), they show a high value of hardness number for position 5 in the A rail. Otherwise the hardness is quite uniform over the sections and from one rail to another, except, of course, for rails from the nickel-chromium ingot No. 3. As shown by the last column of Table III., there is a greater variation in hardness over the section of the A rails than over the C rails, with the single exception of the rails from the ordinary piping steel ingot No. 6; but this latter had had a discard of 13 per cent. in the bloom.

The results obtained by the Maryland Steel Co. for the drop tests are shown in Table IV., those of the inspection, in Table II., physical tests in Table V., and chemical analysis for carbon in Table VI., in which the O and M positions refer to Fig. 7.

Table IV.—*Drop-Test Results.*

100-lb. P.S. section; 3-ft. supports; weight of tup, 2000 lbs.; fall, 15 feet.

Ingot No.	Blow.	Per Set.	Elongation on Base.						
			1st In.	2nd In.	3rd In.	4th In.	5th In.	6th In.	Total.
2	First . . .	1·1	0·03	0·04	0·05	0·05	0·04	0·03	6·24
3	First . . .	0·8	0·03	0·04	0·05	0·05	0·04	0·03	6·24
4	First . . .	1·1	0·02	0·04	0·05	0·05	0·04	0·02	6·22
6	First, pipe at fracture	1·0	0·02	0·03	0·04	0·04	0·03	0·03	6·19
7	First . . .	1·0	0·02	0·03	0·04	0·04	0·04	0·03	6·20
	Second . .	1·9	0·03	0·04	0·06	0·06	0·06	0·06	6·31
8	First, pipe at fracture	1·0	0·02	0·04	0·05	0·05	0·03	0·03	6·22
9	First . . .	1·0	0·02	0·02	0·05	0·05	0·04	0·03	6·21

The drop test, which is supposed to give a measure of the resistance to shock and of the ductility of the steel, shows a practical uniformity in this respect for all the pieces. The appearance of the fractures is shown in Fig. 8.

A comparison of the Brinell hardness (Table III.) and the analysis of carbon segregation (Table VI.) is of some interest. In a general way the increase in carbon content for the A rails from the O to the M positions (of Fig. 7) corresponds with the increase in hardness from the outside to the centre of the rail section (positions 2 to 5, for example). The apparent exceptions to this for rails from ingots 8 and 9 will be explained in the section on microstructure by the presence of an area of ferrite enveloping position 5 but not position M. It will also be noticed that the lessened carbon segregation for the C rails, that is, near the centre of the ingot, accompanies a more uniform distribution of hardness over the section.

Referring now to Table V., the tensile tests show (the nickel-chromium steel excepted) a high degree of uniformity in all respects for the physical properties of the steel from the centre of the various types of ingot as rolled into rail.

It would appear, therefore, that in so far as this limited number of comparisons is indicative, the usual mechanical and

TABLE V.—*Results of Tensile Tests Cut from Centre of Heads of C Rails.*

Ingot No.	Yield Point,[1] Lbs. per Sq. Inch.	Ultimate Strength, Lbs. per Sq. Inch.	Elongation per Cent. in 8 Inches.	Reduction of Area.	Fracture per Cent.
3	98,700	177,300	9·75	27·3	100 silk, cup and cone.
2	69,100	119,600	14·00	25·2	10 silk.
4	69,000	118,600	12·00	26·0	10 silk.
6	69,300	119,300	14·00	27·3	10 silk.
7	67,000	120,600	11·75	23·6	10 silk.
8	69,000	119,600	12·00	20·4	10 silk.
9	68,000	119,000	11·75	20·4	10 silk.

Ingot No.	Analysis.[2]						
	Carbon.	Manganese.	Phosphorus.	Sulphur.	Silicon.	Chromium.	Nickel.
3	0·268	0·41	0·034	0·043	0·195	1·44	3·65
2	0·562	0·99	0·033	0·047	0·169	...	...
4	0·570	0·90	0·040	0·046	0·197	...	...
6	0·580	0·90	0·052	0·054	0·197	...	...
7	0·618	0·93	0·053	0·066	0·197	...	...
8	0·598	0·94	0·041	0·070	0·216	...	...
9	0·610	0·98	0·044	0·057	0·226	...	...

TABLE VI.—*Carbon Analysis of Rails to Show Segregation.*

O and M positions of Fig. 7 for tops of A, B, and C rails.

Ingot No.	A-O.	A-M.	B-O.	B-M.	C-O.	C-M.	Method of Casting.
2	0·540	0·612	0·560	0·556	0·570	0·588	Large end up; special feeding.
3	0·278	0·290	0·250	0·270	0·240	0·272	
4	0·550	0·640	0·560	0·580	0·612	0·580	
6	0·528	0·584	0·536	0·552	0·560	0·558	Small end up; ordinary piping steel.
7	0·550	0·648	0·570	0·598	0·578	0·568	Ordinary rising steel.
8	0·530	0·640	0·570	0·662	0·578	0·588	Special feeding.
9	0·598	0·640	0·580	0·600	0·576	0·588	

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[1] Yield point found by use of dividers and running the machine back until the point was found where there was a permanent stretch.

[2] Analyses shown are from drillings taken from pulled tensile specimens.

chemical tests may not differentiate satisfactorily one type of rail steel from another.

(*b*) *Metallographic Study—Macroscopic Examination.*—Sulphur prints were taken of the front ends of all the A rails as follows:

CLASS I.: *Ingots for Rails made by the Hadfield Process, large end cast up.*—This class, which includes the rails from ingots cast large end up by the Hadfield process, is illustrated by Fig. 9. The macrostructure is very uniform; the sulphur print reveals no marked inhomogeneity throughout the section. The web, which is usually the part consisting of the poorest material, here is practically uniform with the remainder of the section. Only in the A rail of ingot No. 4 is there any decided hint of a laminated structure in the metal of the web. Fig. 13 shows a view of a cross-section of the web of rails 3, 2, 7, and 8. The polished section has been etched with dilute nitric acid. This method reveals a central streak in rail No. 3 which is not shown by the sulphur print. The centre of the web of rail No. 2 is slightly darker, indicating a streak of slight carbon segregation.

CLASS II.: *Ordinary Piping and Rising Ingots for Rails.*—From ordinary piping and rising steel (Figs. 11 and 12) rails Nos. 6 and 7. No. 6 shows no decided inhomogeneity in structure, but has a pipe which extends throughout the entire A and B rails and appears in rail C. At the face of the A rail this pipe has a vertical dimension of $1\frac{5}{16}$ inch; at the beginning of the C rail it has narrowed down to $\frac{10}{16}$ inch. No unusual segregation accompanies this pipe. The sulphur print of the A rail from ingot No. 7 has the usual appearance of material of this kind; the sulphide inclusions are comparatively large and conspicuous.

A section of this rail from ingot No. 7 was also etched with copper-ammonium chloride; its appearance is shown by Fig. 13. The web shows a well-defined dark central streak which is also shown in Fig. 10. Apart from the inhomogeneity in the material of the web, no other pronounced characteristics of poor material are shown by this method of examination.

CLASS III.: *Ingots for Rails made by the Hadfield Process, small end cast up.*—The rails of this class were rolled from Hadfield ingots, which were cast and cooled with the small end up. The macroscopic examination (Fig. 14) shows a structure very different from that of Class I. Extending through the centre of the upper web and head is a soft streak, which upon etching the section with copper-ammonium chloride remains light coloured. The sulphur print indicates that this central core is comparatively free from sulphur. A microscopic examination shows that the metal here is quite free from carbon; it appears as a streak of ferrite containing many inclusions, presumably oxides. This soft central ferrite streak appears characteristic of rails rolled from ingots which have been cast in the inverted position, so far as can be judged from these rails. The soft centre extends to the centre of the ingot. Fig. 15 shows the appearance of No. 8 after etching with copper-ammonium chloride solution. The central streak remains white, indicating that it is comparatively free from carbon. The remainder of the rail has the appearance of good homogeneous material. Rail from ingot No. 9 shows this same characteristic, though not quite so pronounced as in No. 8. Sulphur prints were also taken from the bottom of the E (last in ingot) rails from ingots 8 and 9. These had the same appearance as Fig. 9 of Class I.

Microscopic Examination.—For the examination of the microstructure a cross-section of the web, which is the portion usually having the poorest structure, was taken, and also a sample from the head, midway between the centre and side. Rails from ingots Nos. 2, 3, 7, and 8 were examined thus.

Fig. 10 represents a view of the etched cross-sections of the web (×1) of the four rails examined. Rail No. 3, by this method of etching, shows a central streak somewhat similar to the one noticed in No. 8. By oblique light both of these central streaks appear white. Rails Nos. 2 and 7 show a slightly darker centre, which is due to the segregation of the carbon.

Rail from ingot No. 3 has a microstructure very different from the other rails (Fig. 16). The amount of nickel and chromium (3·5 per cent. and 1·45 per cent. respectively) is apparently sufficient in spite of the low carbon to retard the transformation changes of the steel during the comparatively rapid cooling of the rail, so that the ordinary pearlite-ferrite structure is not found. The microstructure, as a whole, is very fine and uniform; the centre of the web differs principally in the amount of carbon. The metal is in the rather indefinite structural condition of sorbite or troosto-sorbite. The central streak throughout the web which appears rather prominent from a macroscopic view-point is not markedly different from the remainder of the rail microscopically. It differs primarily in the amount of carbon, and therefore in the amount of ferrite, and so the structure is somewhat coarser than throughout the remainder of the rail.

The examination of the A rail from ingot No. 2 (Fig. 17) shows that the carbon segregation in a narrow central streak in the web is sufficient to give the metal the appearance of a eutectoid structure. Apart from this, the microstructure is not unusual, and does not differ much from that of the other rails examined. (From ingots Nos. 7 and 8.)

In spite of the poor structure indicated by the sulphur print for the rail from ingot No. 7, the microstructure appears fairly uniform (Fig. 18). There is but little carbon segregation in the central portions of the web, the metal is rather coarse as to grain size, but apart from this compares rather well with the other rails of this composition examined. The inhomogeneity of the metal, due to the comparatively large sulphide inclusions together with the coarse grain size, is probably responsible for many of the observed physical properties.

In the rail from ingot No. 8 the main point of interest observed is the central longitudinal streak of comparatively pure ferrite, extending throughout the first three rails rolled from the ingot (Fig. 19). This streak is full of inclusions, and has the appearance of rather poor wrought iron; the line of demarcation between it and the surrounding metal is quite sharp and well defined. A section of the lower part of the web beneath this streak of soft metal shows a slight segregation of carbon in the centre. Otherwise the microstructure of the rail shows no unusual features.

The following summary of the metallographic examination may be made:

(*a*) The rails from the ingots of the inverted Hadfield type show a characteristic soft central streak extending throughout the A, B, and C rails.

(*b*) The sulphur print examination indicates a macrostructure for the rails rolled from the usual form of the Hadfield ingots (that is, cast large end up) much more uniform than for those from any of the other ingots.

(*c*) The nickel-chromium steel rail shows a microstructure very different from the others due to the different composition, so that no strict comparison with others is possible.

(*d*) The "pipe" in the rails from ingot No. 6 (piping steel cast in ordinary way) occurs without any pronounced segregation in the neighbourhood of the pipe. This pipe extends well into the C rail even after a top bloom discard of 13 per cent., confirming the characteristics of the split comparison piping ingot No. 10.

(*e*) The macroscopic examination indicates that rails from ingots 2, 3, and 4 are good throughout, from the front face of the A rail; rails from ingot No. 6 are poor throughout some 60 per cent. of its entire length because of the pipe; rails from ingot No. 7 show the appearance of the average rail at the face of the A section; Nos. 8 and 9 show a central streak of soft material which in the case of No. 8 extends through into the C rail. The streak in No. 9 is not so pronounced as in No. 8. The rails from the bottom of the Hadfield ingots cast small end up show no anomalies.

(*f*) The top discard of ingots 2, 3, and 4 could have been reduced, as shown by above examinations.

From the several tables of tests and from the metallographic examination, it is seen that the percentage of ingot available for sound rails of uniform homogeneous structure is 91, 90, and 88 respectively for the specially fed ingots cast large end up, Nos. 2, 3, and 4, as compared with much less percentages of sound metal usually available from ingots cast in the ordinary manner, either of unsound nature or from piped steel not properly fed.

6. GENERAL CONCLUSIONS.

In all, nine ingots were used in this investigation, eight furnished by one of us, all but one of which had approximately the same chemical composition.

The examination of the split ingots shows the great superiority of casting large end up and feeding by the special process, such an ingot being physically sound and uniform throughout and practically free from chemical segregation.

The examination of the rails shows that for ingots cast by the Hadfield process, those cast large end up will give rails of uniform quality free from internal flaws of all kinds; those cast small end up may show a soft region in the web of the A rail, but are otherwise sound. Those cast in the ordinary manner from piping or otherwise unsound steel may or may not give sound rails depending upon the condition of the steel.

In addition to the certainty of producing all sound rails by the special feeding process from ingots cast large end up, there is a great saving in metal and a consequent increase in percentage of sound ingot available for rails—in these experiments an average of 90 per cent. for ingots 2, 3, 4, as compared with about 50 per cent. for the piping ingot and an uncertain amount from the rising type.

The physical and chemical tests to which rails or rail steel are usually subjected do not appear to give an adequate measure of the quality of rails. For example, the results of the tensile and drop tests and chemical analyses would not separate the sound from all the unsound rails here examined. The metallographic examination is a valuable aid in determining the quality of the finished rails.

The question may be asked, is it not worth while to use, in the manufacture of rails, only sound steel which is cast and rolled in such a manner as to make practically *every* rail a sound and safe one? We believe this can be done without excessive cost.

One of the authors was recently present at the casting of ingots by this system from a 16-ton heat, the fluid steel being poured into twenty-one 11-inch ingots, the time occupied being about fifteen to twenty minutes. By means of patching, the sand tops in this system can be used several times, in some cases three, or even four times. It will be seen that no more time is required for the casting operation than for heats of steel poured into ingots made in the ordinary manner. The sand heads are produced very cheaply. The air-blast attachment is fixed in the casting pit, and an ordinary labourer in a few seconds placed them in position for operating the blast on the upper portion of the ingot and sand head, after this is filled with fluid steel from the ladle. The whole cost, including the labour, is probably from 1s. 6d. to 2s. per ton.

There cannot be more convincing evidence that this rail problem must be attacked and solved than the following statement made by Mr. H. W. Belnap, Chief Inspector of Safety Appliances, Interstate Commerce Commission, Washington, D.C.:

> "Broken rails have caused 2762 accidents during that period (twelve years), resulting in death to 175 persons, injury to 6000, and property damage aggregating $3,237,793. On one railway alone there were 2760 rail failures during the months of November and December 1911 and January 1912. The number of rail failures which occur on railroads of the United States is constantly increasing."

With regard to the microstructure work, this has been carried out in a very able manner by Mr. Henry S. Rawdon, of the Bureau of Standards, and we express our best thanks for the valuable assistance rendered.

We are likewise greatly indebted for valuable assistance from several members of the staff of the Bureau of Standards, particularly Messrs. Hillebrand, P. H. Bates, Witmer, and Devries; and finally wish also to take this opportunity of thanking Mr. I. B. Milne and Mr. W. J. Dawson, of Sheffield, for their share in the research and for the care and attention bestowed by them upon the work.

LIST OF PAPERS BY SIR ROBERT HADFIELD ON "SOUND STEEL."

No.	Title.	Name of Institute.	Year.
1.	"On a New Method of Revealing Segregation in Steel Ingots."	Iron and Steel Institute.	1912
2.	"Method of Producing Sound Ingots."	Iron and Steel Institute.	1912
3.	"Plant for Producing Sound Steel Ingots."	American Institute of Mining Engineers.	1913
4.	"Méthode pour Produire des Lingots d'Acier sains et déceler la Ségrégation dans les Lingots d'Acier."	*Revue de Métallurgie.*	1913
5.	"Nouvelle Méthode pour déceler la Ségrégation dans les Lingots d'Acier."	*Revue de Métallurgie.*	1913
6.	"Sound Ingots."	American Institute of Mining Engineers.	1914
7.*	"Sound Steel Ingots and Rails."	American Institute of Mining Engineers.	1915
8.	"Sound Steel for Rails and Structural Purposes."	Franklin Institute.	1915
9.	"Sound Steel for Rails."	Franklin Institute.	1915
10.*	"Sound Steel Ingots and Rails."	Iron and Steel Institute.	1915

* Joint paper by Dr. George K. Burgess.

PLATE I

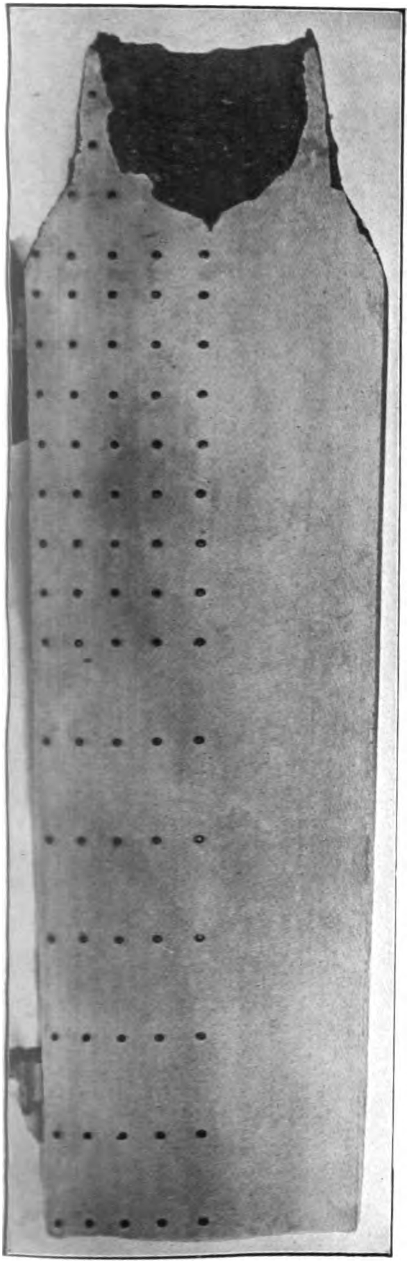


FIG. 1.—Split Hadfield Ingot, showing location of drillings and condition of the interior of ingot.

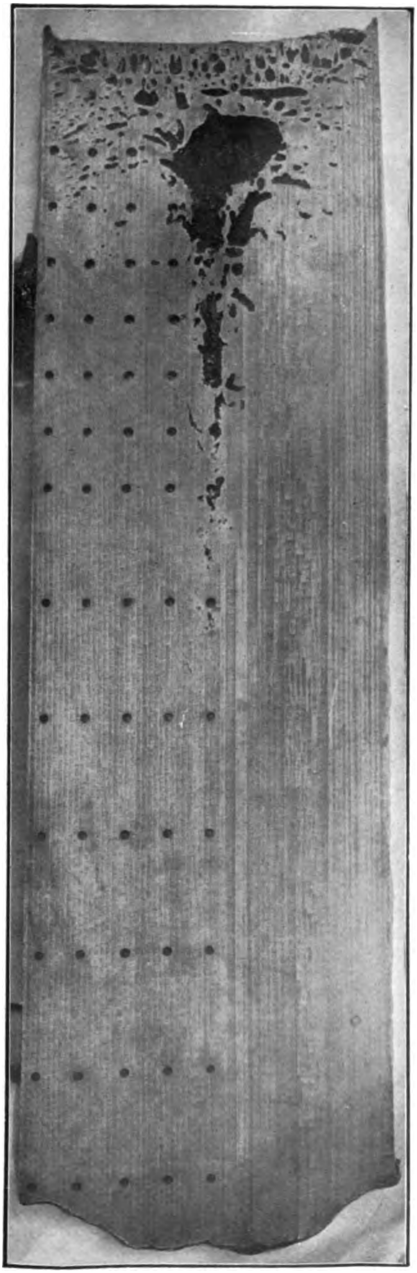


FIG. 2.—Split Comparison Ingot, showing location of drillings and condition of the interior of ingot.

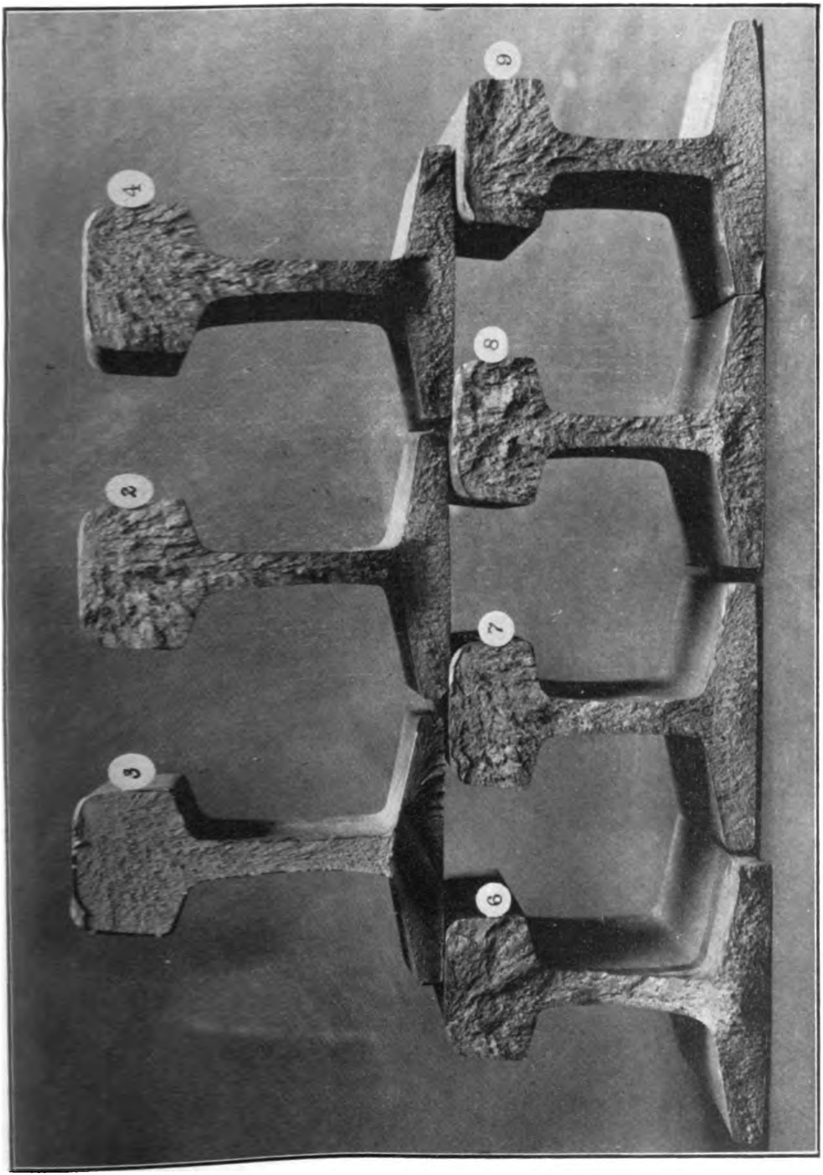


FIG. 8.—The photograph shows the appearance of the fractures due to the drop test.

PLATE III

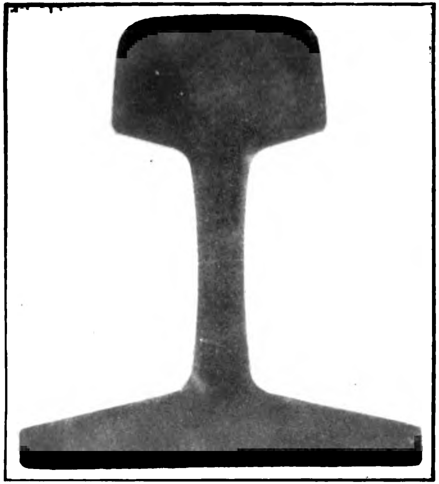


FIG. 9.—Sulphur print of section from front end of A rail from Ingot No. 2, specially fed, cast large end up

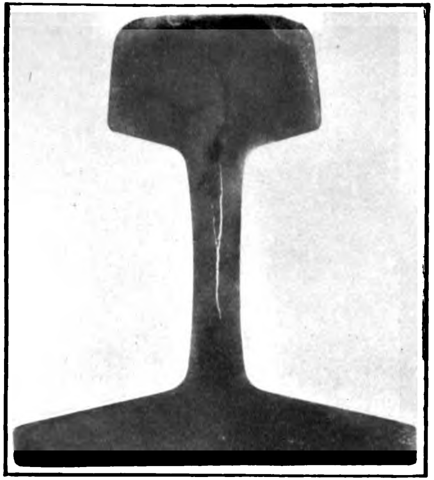


FIG. 11.—Sulphur print of section from front end of A rail from Ingot No. 6, cast in ordinary manner from piping steel. The pipe shown extends into the C rail.

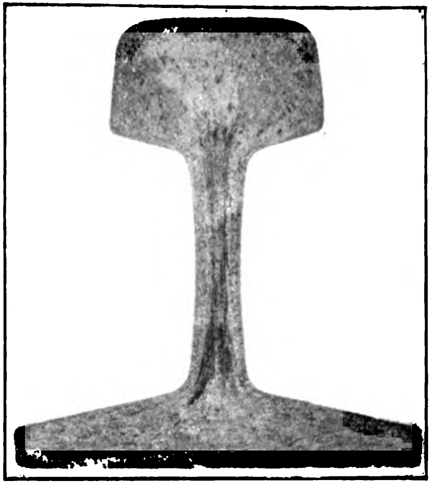


FIG. 12.—Sulphur print of section from front end of A rail from Ingot No. 7, cast in ordinary manner from rising steel.

PLATE IV

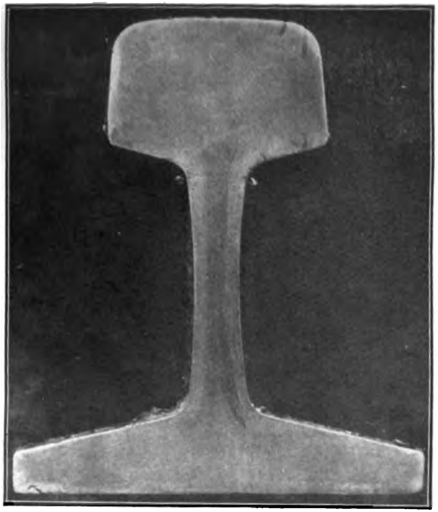


FIG. 13.—View of a section of the A rail of Ingot No. 7 after etching with copper-ammonium chloride solution. Aside from the dark central streak in the web, the appearance is not bad.

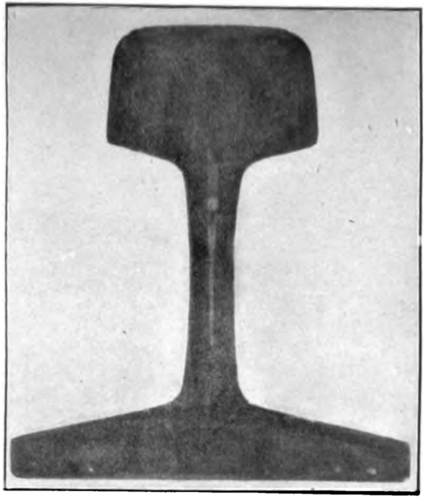


FIG. 14.—Sulphur print of B rail from Ingot No. 8, specially fed, cast small end up.

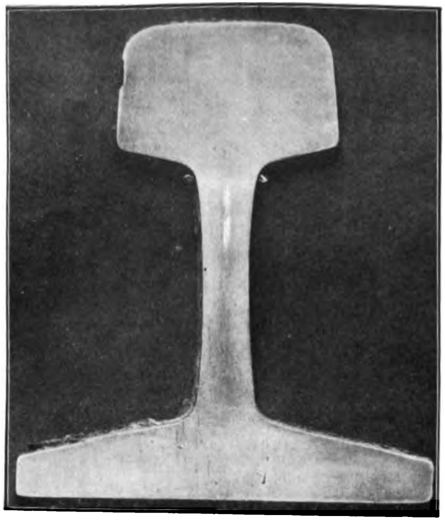


FIG. 15.—View of a section of rail from Ingot No. 8, taken from the A rail after etching with copper-ammonium chloride. The central streak shown by the sulphur print is here shown to be an area low in carbon. No other bad features are shown, otherwise the metal appears very uniform.

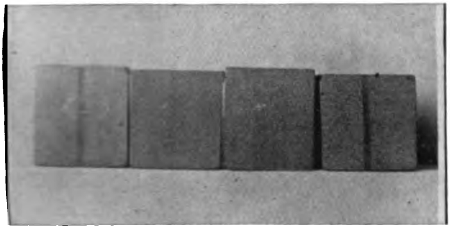
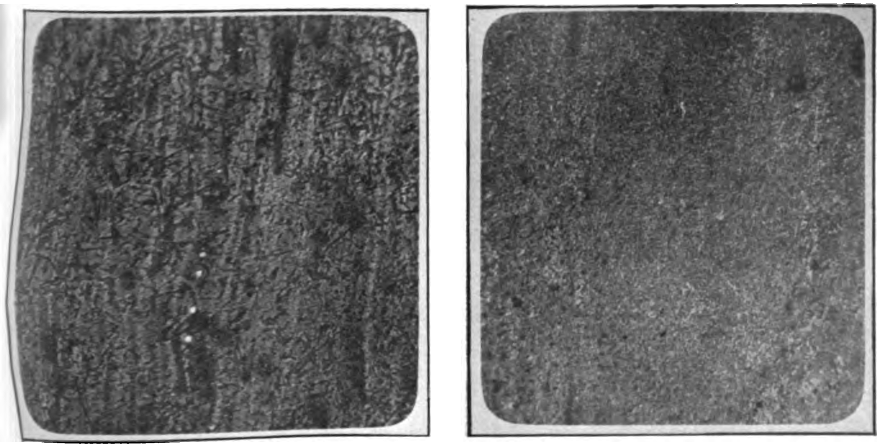


FIG. 10.—Photograph (magnified 1 diameter) of cross-section of the web of rails Nos. 3, 2, 7, and 8 respectively, in order from the left, after etching with nitric acid. By oblique light the central streaks shown in Nos. 3 and 8 appear white in comparison with the remainder of the metal, indicating a lower carbon content in this streak. The darkening of the centres of Nos. 2 and 7 is due to a slightly higher carbon content here.

A



B

C

FIG. 16.—A, B, and C show the microstructure of rail No. 3 (nickel-chromium) in the head, centre of web, and outer portion of web, respectively. Magnified 100 diameters.

PLATE VI

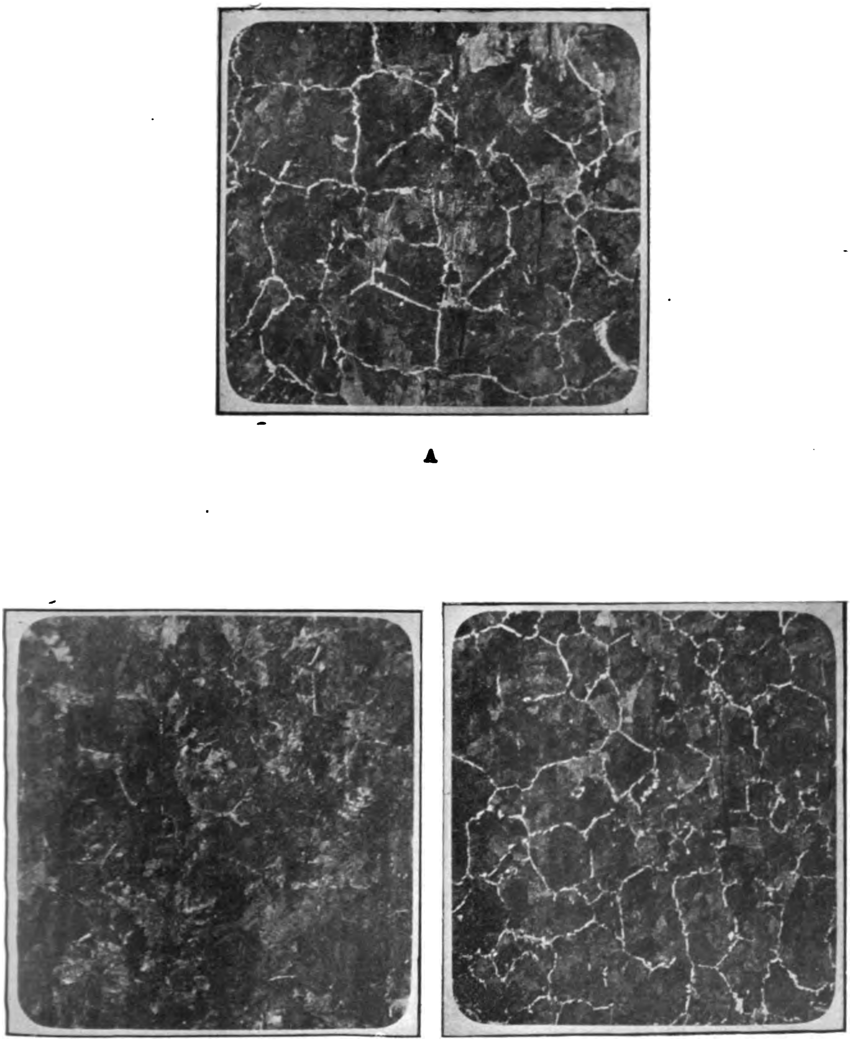


FIG. 17.—A, B, and C show the microstructure of rail No 2 in the head of the rail and central and outer portions of the web, respectively. Magnified 100 diameters.

The main part of the rail has the ferrite-pearlite cell structure usually found in rails of this composition. In the central part of the web the carbon has segregated sufficiently so as to give a structure approaching that of metal of eutectoid composition.

PLATE VII

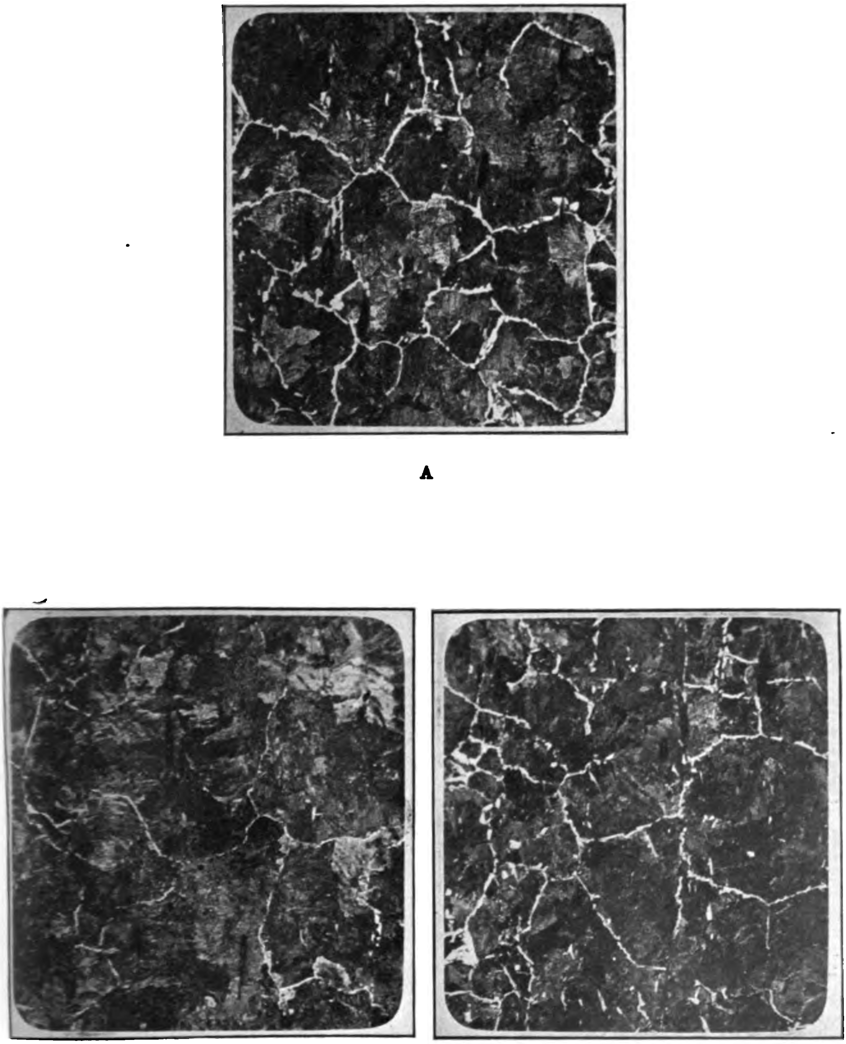


FIG. 18.—A, B, and C show the microstructure of rail No. 7 in the head of the rail and central and outer portions of the web, respectively. Magnified 100 diameters.
The microstructure indicates but little segregation of the carbon in the central portion of the web.

PLATE VIII

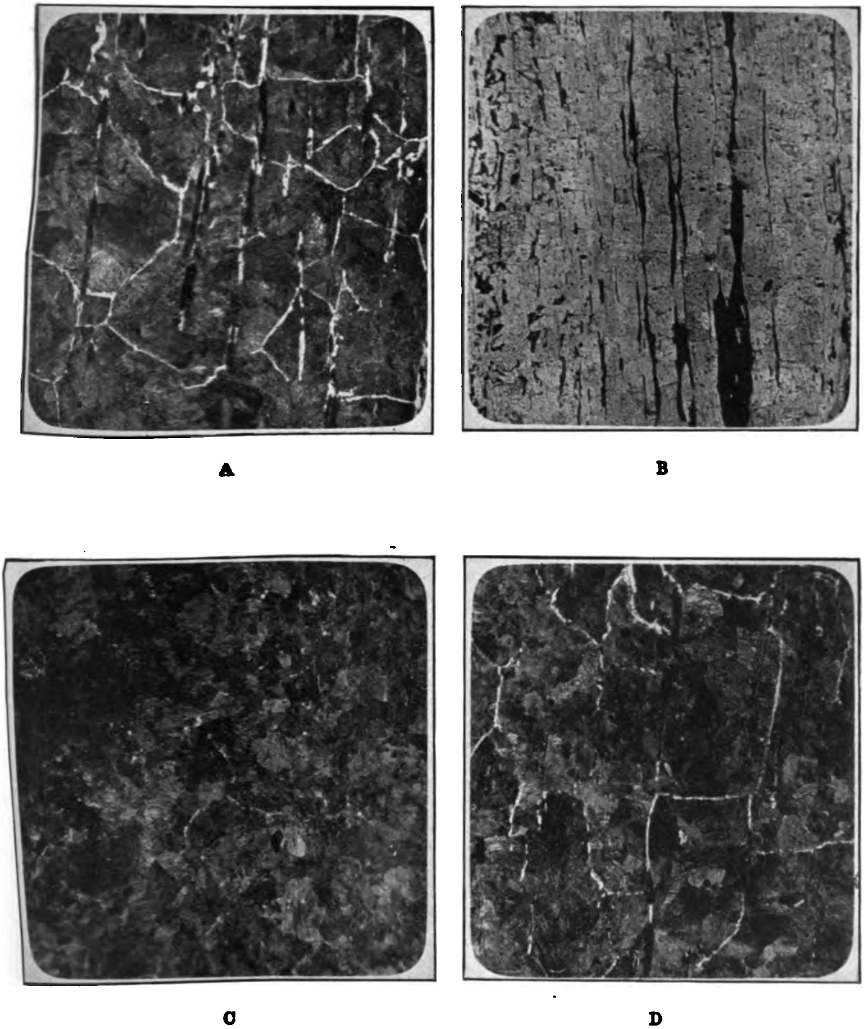


FIG. 19.—Microphotographs showing the microstructure of rail No. 8. Magnified 100 diameters.

A.—Microstructure typical of the metal of the greater part of the head of the rail.

B.—Structure of the soft central streak in the upper part of the web. The metal is ferrite containing numerous inclusions.

C.—Structure of the centre of the lower part of the web. This is outside the area of the soft ferrite layer; the carbon is high enough to give the metal a eutectoid structure.

D.—Structure of the outer portion of the web.

DISCUSSION.

Sir **Robert Hadfield**, F.R.S., Past-President, said the research embodied in the paper was a continuation of that detailed in the two papers he contributed to the *Journal* of the Institute in 1912. The particular research arose as the result of some experiments in which he poured molten copper on to the top portion of an ordinary steel ingot about ten minutes after it had been cast. It was then found that the copper penetrated even to the bottom of the ingot, thus showing how important it was to maintain ferrostatic pressure by feeding methods for much longer than was ordinarily thought necessary. If that were not done, satisfactory ingots, free from unsoundness, piping, and segregation, could not be obtained. The waste in steel-making to-day was simply gigantic; no other adjective met the case. For example, the world's estimated output of steel was about 75,000,000 tons per annum, and probably at least 25 per cent. to 30 per cent. was wasted in the form of scrap. If that could be reduced by one-half, there would be a saving of no less than about 10,000,000 tons. Moreover, there was the serious loss from oxidation to be considered. Each time the steel was remelted in the form of scrap there was a certain amount of loss which was never recovered. As an illustration of the waste in scrap, he would instance, for example, the working of 25-ton to 40-ton open-hearth furnaces, with an average output of 400 to 500 tons per week. By avoiding the waste he had mentioned about 600 furnaces could be shut down if methods of making sound steel were adopted, and there would be still the same steel available for use.

He referred to and exhibited some photographs of English rails which had failed, and said that in these days of modern progress it appeared to be a slur on the metallurgical art to continue to make any such rails. There was not the slightest necessity to make a single unsound ingot, but if they were made, it should be possible to detect them before they were put into service. Many ingots were perfectly sound, but there were cases in which the products from ingots contained hidden flaws which it was impossible to detect except by cutting open or testing in some other way.

He also showed two photographs, one illustrating the casting operation, and the other the casting after the tops had been removed. He pointed out that the new method occupied no more time than the old, and resulted in the production of ingots which gave perfectly safe products. He also exhibited two ingots, one an 18-in. ingot, weighing about 2½ tons, and the other cut open longitudinally, in which not a trace of piping, unsoundness, or segregation could be found. Over 100 of such ingots were now being rolled in America, and careful tests were being made of the rails produced from them. The carbon in the particular ingot shown was 0·65 per cent. He also showed a mild-steel ingot with 0·18 per cent. of carbon. He also exhibited transverse sections showing the "discard," and pointed out that with 15 per cent. discard an absolutely perfect etching could be obtained.

In addition to the acknowledgments made in the paper, he wished to take the opportunity of expressing his thanks to his colleague Dr. Burgess, who had carried out the investigation in Washington and performed the large number of tests which such a research required.

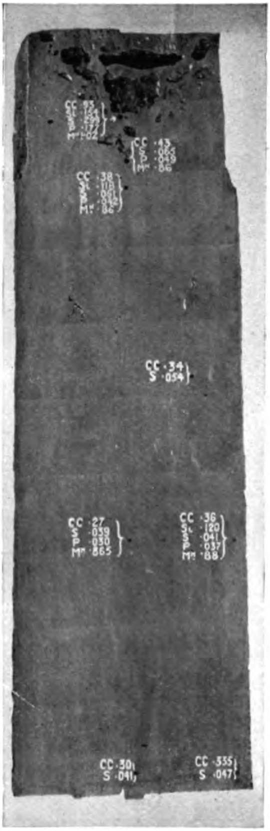
Every ingot made by the particular method had a recess or cavity, and it was now found, after making some 20,000 or 30,000 ingots, that it was possible to predict exactly what the cubic capacity of the cavity would be. It was found that with an 18-in. ingot the average showed that about 140 lbs. of fluid steel passed from the upper or head portion to the body of the ingot. In an ordinary ingot that did not take place. If the steel were of a piping nature a certain amount would pass down, but it was impossible to be sure of getting the whole. Sometimes an excellent ingot could be obtained in the ordinary way, but it was impossible to avoid the production of various grades, some of them giving dangerous steel. The amount of the material which went from the top into the interior of the mould would vary according to the temperature of the steel, but this was in small controllable limits. Still more important was it that the ferrostatic pressure should be kept up. It was apt to be forgotten that at one time in its life history steel was fluid like water, and subject to ferrostatic pressure, just as water was subject to hydrostatic pressure. The steel was kept fluid as long as possible in the upper portion, and consequently by the system now described the ferrostatic pressure lasted (for 18-in. ingots) very much longer than usual. The result was that nearly 1¼ cwts. of steel passed down and filled up certain defects which were otherwise liable to occur, and in most cases did occur. He (Sir Robert) was not a rail-maker and did not wish to interfere with the manufacture of rails, and he had only put forward the paper with the object of removing the serious slur on the metallurgist that he produced material of uncertain composition. If he were a rail user it would appear to him much more logical to inspect the original product, and detect any defects or any objectionable points in the first stage. It was easy to put a small rod inside the cavity and find whether this was of a certain depth, and if it were found to be so the ingot could be rolled into any product with the certainty of securing perfect material. It was possible to obtain with such ingots 90 per cent. of absolutely sound products.

Two further photographs were shown, one of an ingot which was slightly rising, and another in which the steel was settling. He (Sir Robert) said he would challenge anybody, without cutting open the ingots, to tell in what way they were wrong. If the material were of a rising nature, the ingot would be full of blowholes. If the steel were very soft, the blowholes could to some extent be closed up in subsequent heating processes, but he was daily coming more

PAIR OF BOTTOM POURED INGOTS.

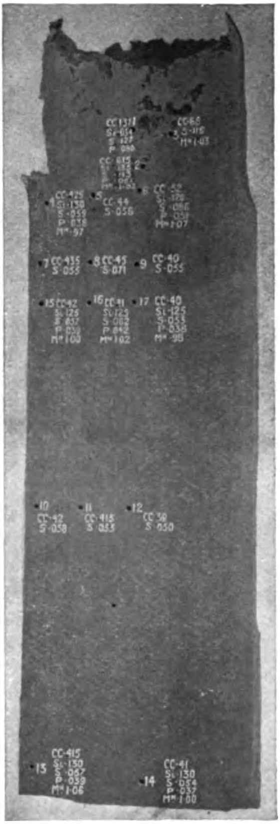
160
Big end up.

160
Small end up.



TOP POURED INGOT.

163



1 ounce of aluminium per ton.

Average analysis of heat as given by pit sample :—

	Per Cent.
Combined carbon	0·32
Silicon	0·130
Sulphur	0·046
Phosphorus	0·035
Manganese	0·82

Size of ingot	22 ins. by 20 ins.
Length of ingot	6 ft. 0 ins.
Weight of ingot	7800 lbs.

strongly to the opinion that the blowholes should never be there. Nothing could be more severe than the test required in the manufacture of armour-piercing projectiles; the slightest imperfection in the material was of the utmost gravity, and no one would think of using steel in which there were any blowholes even though they were supposed to be closed up. The common impression was that one could wash-weld unsound steel and improve its quality, but the inherent weakness was still there. Consequently, why not make sound steel to start with? At the present time he had made no steel containing less than 0·15 per cent. of carbon, but there was not the slightest difficulty in making the lowest possible or the highest possible carbon steel. The method he had described was very simple, and the saving obtained by the reduction of waste more than paid for any expense in carrying it out. The value of the system at the present time was very important. In his manufacture of steel for high explosive projectiles he estimated that his firm was getting the same number of shells from 750 tons of ingot that would have been obtained from 1000 tons of ingots in the ordinary way. It was of enormous value to have a saving of that kind; not only of material but of time as well. If it were possible to help other projectile makers in Great Britain, the whole of the research which the Institute had allowed him to bring before them would be of benefit to the nation.

Mr. B. Talbot (Middlesbrough) said that on reading the paper he could not help being struck by the manner in which the authors spoke of the overwhelming superiority of the ingots which had been cast by Sir Robert's feeding process. The questions naturally arose: if that great superiority existed, was it brought about by that method of feeding the sink-head? and, if a comparison had to be made, would it not be between ingots having the same characteristics? and further, if sink-heads had to be used, should not the comparison be between the fed ingot and an ingot cast with the ordinary sink-head, but not fed? In going through the paper, he noticed these questions had not been dealt with, as the same class of ingot had not been used for the comparison. In Table I. there was a list of the ingots used. Some of those ingots were cast with the large end up, others with the small end up, using the Hadfield system, and as a comparison ingot, there was one which he presumed was ordinary American high-phosphorus acid Bessemer steel. It was to be presumed that the eight other ingots obtained from Sheffield were of acid open-hearth steel made under the well-known careful and expensive Sheffield system. It would be also noted that in all the Sheffield ingots there was 0·2 per cent. of added silicon. It was said that in ingot No. 1, which was used for cutting in two, longitudinally down its centre, and was also plotted for analysis over half its face, that 0·1 per cent. of aluminium was added, which if correct meant over 2 lbs. per ton of steel. That was an amount of aluminium which was never used in ordinary steel manufacture. Why an ingot should have been used with that extraordinary addition when it was well known that aluminium decreased segregation, to illustrate the absence of segregation, as well as its well-known effect in promoting solidity, he (Mr. Talbot) could not understand, unless the comparison ingot were treated in the same way. Again, why should an ingot, specially made in Sheffield, with 0·20 per cent. silicon and 0·1 per cent. of aluminium added, be compared with an ordinary acid Bessemer American ingot, to which neither silicon nor aluminium additions were made? It would have been more satisfactory if the comparison ingot had been made by the basic open-hearth process with its well-known low phosphorus and sulphur contents. Seeing that in the year 1914, out of 1,850,000 tons of rails made in the United States, over 1,500,000, or 78 per cent., were of basic open-hearth steel, and only 323,000 tons, or something over 16 per cent., were acid Bessemer, it might have been thought better to have made the comparison on the 78 per cent. proportion rather than on the 16 per cent. Again, in Table I., ingot No. 7 was spoken of as being ordinary rail steel of rising or boiling nature, and its analysis was practically identical with No. 6, which was spoken of as ordinary rail steel which piped. In both cases the silicon was 0·2 per cent., and he presumed that it was added silicon in both cases. If so, why should the one pipe and the other be of a rising nature? In all his experience, he had never seen an ingot of a rising or boiling nature in which 0·2 per cent. of added silicon was found in the steel after it was cast. The sulphur print of the rail from ingot No. 7, which was illustrated in Fig. 12, had indications of not being piping steel, but if there were only 5 per cent. taken off the top end of the bloom and the sulphur print was taken at that point, it was not surprising, seeing that in that particular ingot the sulphur was high, being 0·08 per cent. If the steel had 0·04 or 0·05 per cent. of sulphur, as had most of the other ingots, the contrast in the print would not have been so great.

In Table II. details of the rolling and inspection of the rails were given. It was not stated, however, whether the sink-head was cut off before the cold ingot was charged. He presumed it was not, and that the hollow-ended ingot was rolled down into a bloom without first having the sink-head portion removed. He would like to know whether the sink-head were removed before charging, and if so, if the weight were included in the percentage of the top-bloom butt given in the table? If the sink-head were not detached, was there no trouble with the hollow end as shown in Fig. 1 of Plate I. in rolling it down to a suitable-sized bloom for the rail mill? He was struck by the large percentage of seconds from the Hadfield ingots in Table II. Possibly the American classification differed from English practice, and many of those seconds could be used in the track. It would be interesting, therefore, to know the actual percentage of defectives out of the seconds which could not be used, and what percentage of seconds was generally obtained in American practice. An immense amount of piping was met with in ingot No. 6, as, according to the return, 90 per cent. of the rails were seconds largely due to pipe. As there were many thousands of tons of rails made with 0·2 per cent. silicon in them, it was evident that the pipe did not in ordinary practice extend into the bottom portion of the ingot, as Sir Robert's results would lead it to be believed. If such an ingot were cast and purposely allowed to go cold there would be of course no doubt that piping would be more developed than if the ingot were charged hot and rolled direct as in ordinary practice.

On page 60 of the paper, when dealing with the ingots cast by the Hadfield process with the small end up, Sir Robert stated that under the microscope there was seen to be a soft streak, and that the soft centre extended to the centre of the ingot; also that the central streak remained white, indicating that it was comparatively free from carbon. Judging from those indications, Sir Robert stated "this soft central ferrite streak appears characteristic of rails rolled from ingots which have been cast in the inverted position, so far as can be judged from these rails." By "inverted position" Sir Robert doubtless meant the ordinary way. Upon what grounds was such a statement made? If Sir Robert would look at his comparison American ingot, could he show any spot in that ingot where the pure iron could be found? The fact was that erratic metal with slag inclusions was often found in pipes which had not been properly filled during the solidification of the ingot, and it was possible that the streak which Sir Robert found in his rail, as shown in Figs. 14 and 15 and also in Micrograph B of Plate VIII., was the remains of a pipe and was due to the filling of the pipe by metal oxidised under Sir Robert's blowpipe treatment from the sink-head. If Sir Robert had shown the extent of the pure iron in the section of an ingot cut open, it would have been more satisfactory than simply giving the central streak as shown in the rails. He would like Sir Robert to explain how he accounted for metal quite free from carbon being in such a position, and whether he could find it by analysis.

Another point which required explanation was the statement that casting big end up was superior to casting with the small end up, which was the invariable custom in rail- and many other steel-works. Whilst Sir Robert's conclusion might be correct for small ingots, it was doubtful whether it were safe to dogmatise for all sizes of ingots. He had had some photographs prepared of ingots of a weight in common use in rail-works, namely, some 3½-ton ingots, which had all been cut through the centre longitudinally in order to see what the results really were. As Sir Robert used a refractory top on his mould, he (Mr. Talbot) had done the same, so as to make a fair comparison. Personally, he was a believer in the brick-lined top, when it was desired to reduce the piping in the ingot, or at any rate to bring the pipe nearer to the top, and it was to the use of that well-known device that he attributed Sir Robert's better results, rather than to the special blowpipe arrangement, which he used in addition.

The ingots illustrated tended to show that the cavities were all in the sink-head portion, and that the remainder of the ingots were perfectly solid. Ingot No. 163 (Plate IX.) was a top-cast ingot with a brick-lined sink-head. It would be seen that it was perfectly solid below the sink-head, and that the analysis was normal just below that. Ingots marked No. 160 were a pair of bottom-cast ingots filled at the same time from the same central runner. In the one case the ingot was cast with a larger end at its base, and in the other the ingot mould had been reversed to permit of its larger end being at the top. The result was that, if anything, the ingot cast with the small end at the top, in the ordinary way, was a better ingot than the one cast in the way so strongly recommended in the paper. The ordinary ingot was normal in its analysis at the base of the brick lining, containing 0·38 per cent. of carbon and 0·061 per cent. of sulphur in the centre of the ingot at that point, whilst its companion ingot at the same point contained 0·51 per cent. of carbon and 0·096 per cent. of sulphur. For reasons such as those, whilst Sir Robert might get different results on an ingot of, say, 1 ton in weight or less, it did not follow at all that the same results would be found in an ingot of three or four times that weight, as the photographs went to prove.

Photographs were also shown of several experimental ingots, following as far as possible Sir Robert Hadfield's method, as his (Mr. Talbot's) firm was always desirous of obtaining information respecting anything which would improve their practice. One of these photographs showed the typical crater formation which Sir Robert advocated. That ingot measured 24 by 20 inches, and weighed about 3½ tons. The carbon, which should have averaged 0·76 per cent., was 1·97 per cent. at the base of the crater, and was still 0·97 per cent. carbon at a distance of 18 per cent. in weight from its top. In fact, the discard should be cut off at that point at least. He admitted, of course, that better results would probably be attained with practice. It appeared to him, however, that with the conditions they had to work under, the risk of carbon impregnation was very great and difficult to avoid. A photograph of another experimental ingot of somewhat lower carbon content than the other, made by the same method, was shown. They had not obtained the typical crater formation in the top which Sir Robert said was necessary, but they had again the carbon impregnation. There were also indications of a small pipe below the sink-head, but that was probably due to the fact that the ingot was not charged into a heating furnace with its initial high heat, but was allowed to cool off in the open air, rather than to the fact that a deep crater was not formed. There was no area around the pipe or in the centre of the ingot that was comparatively free from carbon, as stated on page 60. The analyses and soundness, compared with those of the other ingots which had been cast with the brick-lined tops only, showed no practical superiority in ingots of that size. In making the foregoing remarks, he did not want it to be understood that he considered Sir Robert's method was not useful with small ingots for some purposes, as everyone knew that the ordinary sink-head even without his improvement had proved itself of great value, but he (Mr. Talbot) desired to point out that there were considerable difficulties in applying that system to ingots for rails. All modern rail mills cast their ingots on cars, and the old-fashioned pit was not used; that implied a mould cast small end up, and ingots of a weight between 3 and 4 tons. As he had said before, it was his (Mr. Talbot's) belief that there would be no practical difference, when using an ingot of that size with a sink-head, between one cast big end up and one cast with the small end up; but if the big end must be up, it would be necessary to rebuild the casting and stripping arrangements. An ingot of the size in common use would probably take an hour and a half to give the typical formation in the sink-head of the Hadfield ingot. If that were so, then the mould in which that ingot was cast would be red-hot before it was stripped, with the result that the life of the mould would be very much decreased. Would such an ingot be capable of being rolled down rapidly into a 7 by 7 inch bloom in a modern cogging mill—at which no man was at the rolls—without giving trouble from the hollow end there depicted, with the result of possibly turning the piece down, and so increasing scrap and reducing output? If there were trouble, the hollow end would have to be cut off before rolling, and, as it was not practical to allow a rail ingot to become cold—because, if it were necessary to charge cold, the cure would be worse than the disease—some method would have to be adopted to cut off the hollow head whilst the ingot was hot. Rails had to be sold at a very low price, and it would not be profitable to use "gun-steel" methods in their manufacture, and the system advocated in the paper meant a considerable addition to their cost, which would be further increased if an addition of 0·10 per cent. of aluminium was necessary. It would be more economical to discard a few per cent. more of the ingot in present practice than to attempt to carry out Sir Robert's method in mills which, to run economically, required from 500 to 1000 tons of ingots every twelve hours. Sir Robert had referred to the method for eliminating the pipe in ingots, which he (Mr. Talbot) brought before the Institute in 1913. He did not think, however, that the result he had hoped to accomplish, namely, to take solid piping steel and compress the top portion of such an ingot before it was quite solid in the piped area, had been quite grasped by Sir Robert. Ingot No. 10 in the paper, as shown in Fig. 2, which Sir Robert said might be improved by compression whilst liquid in its centre, was certainly not the ingot which he would take, and, whilst compression would improve it, there was no reason to take one of that type. Neither would British rail makers accept the statement that that ingot was probably typical of what they produced. The problem, shortly stated, was to use means whereby the total ingot was made into a solid bloom, and, as the ingot was solid except in the top portion, which was the portion squeezed, the typical formation was now confined to that part of the ingot only which was otherwise usually piped and segregated, but which was now obtained as a solid bloom with a typical formation. As that part was solid, it could be put into a commercial product; and, if there were evidences of segregation, it would be put into a product where such objections were not considered. He would not need to say more about that at present, except that he was still working on the subject, and that progress had been made in simplifying the original method. Probably the results could be better described in a future paper. He noticed that Sir Robert coupled Dr. Stead's name with his (the speaker's) when referring to liquid squeezing. He trusted, however, that no responsibility would attach to his friend if the metallurgical results obtained were not commercially applied elsewhere, as he desired to take that entirely upon his own shoulders, and Dr. Stead had numerous problems of his own.

Mr. **Greville Jones** (Middlesbrough) said it seemed to him a pity that, when Sir Robert was investigating such a very important question, he did not make a comparison with British rails, as well as with American ones. Large quantities of rails were being made in Great Britain with regard to which many manufacturers received very few complaints, and they therefore concluded that the rails they manufactured must be fairly good.

Mr. W. **Dawson** (Sheffield) thought the remarks Mr. Talbot had made were hardly fair, as that gentleman had not appreciated the object of the paper, which was to show the two extremes of unsoundness and piping on the one hand and of what might be called an absolutely good, sound ingot on the other. He (Mr. Dawson) had been fairly closely associated with the work that had been carried out, and he endorsed everything that was contained in the paper. It seemed to him that if the members would inspect the specimens shown, the results would speak for themselves.

Mr. C. E. **Stromeyer** (Manchester) said he welcomed not only the paper but the process described, not so much on account of the reduction of cost, which was more a matter for the manufacturers, but for the fact that by reducing the amount of scrap from the Bessemer ingots it was less likely bad material would get into the open-hearth furnace than was at present the case. He strongly suspected that many failures among ship and boiler plates were largely due to appreciable amounts of Bessemer scrap getting into the open-hearth furnace, and that was one reason why he welcomed the paper. He believed, however, that its value would have been still greater if the question of quality and the question of piping had been kept separate. He could not see that the method described would in any way improve the general quality, although it might reduce the piping. The quality of the material depended upon the impurities in the steel.

For the same reason he did not think the remark made at the end of the paper by the American inspector in regard to the number of failures in America was pertinent, because he did not think the process would reduce the number of failures. Fractured rails were not due to piping but to defective material. He believed recent experiences proved that bad qualities of steel were accentuated in cold weather. He had an experience of that kind a good many years ago when some failures occurred, and on making tests both at ordinary temperatures and with freezing temperatures he found that the good steels behaved practically as well under cold as they did under ordinary conditions, but that the bad qualities were very much worse at cold than at ordinary temperatures. Seeing that most of the failures in America occurred in November, during the cold months, it seemed to him that the quality of the material was defective, and that the failures were not due to piping in the rails.

Mr. W. H. **Hewlett**, Vice-President, thought the paper should be welcomed by the Institute, because it dealt with the question of quality by the reduction that was caused in the segregation. Segregation was very detrimental indeed to most steels that were produced, and if a sound steel could be obtained not only by reducing the piping but by reducing the segregation, and thus be made uniform, he thought it would be of very great service to the industry.

Mr. F. W. **Harbord** (London) said that all the members welcomed any process which gave sounder ingots, and certainly a process which prevented blowholes was one, as Sir Robert Hadfield had pointed out, which all manufacturers had been aiming at. He desired to ask Sir Robert if he had the figures for the percentages of first and second quality rails from the American ordinary ingot No. 10, as these figures did not appear to be given in the table on page 53. The percentages of seconds given in the table seemed to him to be extraordinarily high in the case of some of the rails, and a very good comparison would be obtained if Sir Robert had the figures for the American ingot.

Mr. T. **Twynam** (Middlesbrough) inquired whether Sir Robert had found any increase in carbon in the top part of the ingot just below the crater, because it seemed to him rather dangerous to have in that position fluid steel, with carbon and an air-blast on it. The heating must increase very appreciably up to that point, and it was to be assumed that carbon impregnation would take place. He did not know whether he was in order in referring to the figures that Mr. Talbot had previously quoted, but in some experiments which were made, following the directions given in the paper, an impregnation of carbon had certainly been found below the cavity to a very large extent. He desired to ask if Sir Robert had obtained the same result, because it was rather a dangerous thing to have such a segregation of carbon at that place. The actual sections which Sir Robert had shown were very striking, but they did not show whether there was any segregation of carbon at the place he mentioned.

Professor A. **McWilliam** (Kalimati, India) said he could not be said to be prejudiced in favour of Sir Robert Hadfield's method, because in one of those interesting addresses that Sir Robert gave at the annual meetings of his firm, the reports of which were read all over India, he had advocated the abolition of himself (Prof. McWilliam) and all his class of inspectors. He had made a little private semi-humorous protest to Sir Robert on the point, and he was very glad that Sir Robert had altered his policy with regard to inspectors. Sir Robert now wished to saddle them with the very onerous, although the very pleasing duty, of taking the manufacturer by the nape of the neck and stopping him at the beginning. As a Government inspector he would be quite delighted to do so, provided it was embodied in the specification and accepted by the manufacturer, and he thought it would be a very good thing if such a plan were adopted. A tremendous responsibility, however, would be thrown on the inspector, and it would be necessary to have very good men as inspectors to carry out the work efficiently. He did not know whether Sir Robert would like to have anyone not an expert to decide when the steel would not produce a good rail and when it would produce a good rail. Although personally he would have no objection to the task, he thought that part of the work was best left to the manufacturer, and that the inspector should, unless otherwise authorised by the specification, have regard to the final product only, and examine that as well as he possibly could. The question was one of very great difficulty. On the one hand, there were rails with seams on them produced from ingots that had rising tops, so that the inspector did not trouble about pipes in those cases because he knew they would not be there. On the other hand, a number of rails had an excellent appearance with beautiful skins, but it was necessary to beware of the ends of such rails because piping was very likely to exist. If buyers could make the manufacturers produce regularly such ingots as Sir Robert had described, he thought they would be getting very near to the ideal conditions which Sir Robert had emphasized previously in different circumstances, namely, the total abolition of the inspector, because then a material would be obtained which had a beautiful smooth skin, which gave a good analysis, which stood the drop test well, and it would no longer be necessary to be afraid of pipes. Speaking quite seriously, the members knew he (Professor McWilliam) had for years and years advocated that the way to make steel was, in his opinion, not to make it with just sufficient blowholes to produce a level top, because that was a very elusive method; the manufacturer did not know when he had done it, unless it rose slightly—but to make the material solid and to do away with the piping in some way or another. That was the ideal, although it seemed to him that it was not being sought with sufficient zeal at the present time. If Sir Robert Hadfield's paper, and similar papers, led the makers really to tackle the subject and to do away with both blowholes and pipes by the method advocated by Mr. Talbot or by Sir Robert Hadfield, or by any other method, it would allow the inspector to sleep more easily at night.

Sir **Robert Hadfield**, in reply, said that he would only be able in the short time at his disposal to reply to a few of the points that had been raised, and with the remainder he would deal in a written communication. He would have been very pleased if the discussion could have been continued, because it seemed to him very few of the speakers had touched the question of the whole object of the research, which was to guarantee ingots that would produce certain results with a perfectly sound material. If Mr. Talbot could do that by his method, well and good. There were, no doubt, many methods by which it could be accomplished as well as his own. His paper was simply an illustration of studying the principle of how to get over the troubles of piping and segregation. He wished, in the first place, to tell Mr. Talbot that all the steel described and exhibited was made out of convertors and not by the open-hearth process at all. Mr. Talbot seemed to attach a great deal of importance to the seconds of the material. If he would kindly study the paper a little more closely he would find a statement on page 52 which explained why the seconds were heavy in that particular ingot. It was there pointed out that, through a misunderstanding, a considerable portion of the top bloom crops were cut off instead of being rolled on to the finished rail. That was a pure accident. If Mr. Talbot would make an ingot exactly on the lines indicated in the paper he would be able to get something like 90 per cent. of good material. If he could do better than he (Sir Robert) had done, he would be very glad to hear of it. At the same time he did not think he could. The crux of the whole matter was that when the system was first introduced it was placed before the Government, and, as several of the members were aware, the War Department and the Admiralty were very stringent in their requirements. The Government passed the material through a most severe inspection—his friend, Mr. Ellis, would confirm what he said in that respect. There was no more rigorous inspection test made—and quite rightly so—than that carried out by the British Government. It was only a few days ago he saw a number of projectiles made for a foreign government, and the product was not one which the British Government would have accepted. As he had previously stated, before the matter was carried out in practical effect the ingots were submitted to the British Government, who asked that one or two of them should be cut open. That was done, and they were much pleased with the results. What did the Government do next? Before the research was completed, and before they would accept the method, 120 ingots were cut open. If 120 ingots, made over a period of six, seven, or eight months, were cut open and not a single defective one could be found, he thought it was a very good proof that the method was a successful one. He was rather surprised to hear Mr. Talbot's criticisms. In the first place, Mr. Talbot made an ingot, not by the method described in the paper, and then compared it with an ingot made by the method described. He understood Mr. Talbot to say he made one ingot, copying the method described in the paper, putting firebricks at the top, and compared the result obtained from that ingot with the ingot described in the paper. It was not possible to make a fair comparison unless exactly the method described was copied. He was sure the members would agree with him in that, and he could not therefore admit Mr. Talbot's criticism in that respect for one moment. One hundred and twenty ingots made by the methods described in the paper had been cut open by the British Government. He asked Mr. Talbot, or anyone else, to let 120 of their ingots be cut open, and if they obtained as good results as those described in the paper—he hoped they would be better—he would be only too pleased to congratulate them. It was no doubt an advantage to make the ingot with the big end up. It was necessary to have pressure. That was again a question of ferrostatic pressure, and by having the big end up there was naturally a bigger pressure, and a better result was obtained. The best answer to all the criticism that had been made was that about 100 ingots, made in exactly the same manner as the sample one exhibited, were now being rolled in America, and it would be interesting to see the results that were obtained. He thought Mr. Stromeyer had missed the point when he said that the material described would not prevent the making of defective rails. Personally he thought it would, and the proof of it was contained in the etching. It was there proved that the material at the top was quite as good as at the bottom, and if it was free from defects it must be a better product. Really the only practical point that had been raised in the discussion was that mentioned by Mr. Twynam, who had asked what would be the effect of carbon on the top of the ingot. When 9 or 10 per cent. of the discard was cut off, all trace of the carburisation was removed. Very careful tests were made from all the ingots cut up, and if there was the slightest increase in the percentage of carbon above the maximum, the material would have been rejected. The material had to satisfy the Government inspectors. Nearly 70,000 tons of ingots had been made in the manner described, and so far there had not been a single rejection. He thought that was the best answer to the criticisms that had been raised.

The CHAIRMAN, in proposing a very cordial vote of thanks to Sir Robert Hadfield for his very interesting and instructive paper, said there was no doubt that, however much or little the members might differ from Sir Robert in respect of some of the statements and figures given in the paper—(for instance, as a steel-maker he ventured to hope that most makers produced an ingot with more than 50 per cent. of good material in it)—they would all agree that the object Sir Robert had in view, namely, how to get the maximum amount of sound steel out of an ingot, was one of the most important before the steel-maker at the present day. Sir Robert was therefore entitled to receive their very best thanks for the trouble he had taken.

CORRESPONDENCE.

Dr. W. H. Hatfield (Sheffield) wrote that he had read the paper with considerable interest. The subject of making perfectly sound steel was one which was extremely important at the present time. Sir Robert Hadfield was to be congratulated upon the reduction in scrap which the employment of his method had resulted in as regards his own works. The result was, of course, less scrap and more shells, which, at the present time, was a fact of more than merely metallurgical interest. It was obvious to anyone who had thoroughly studied the production of sound ingots that a method consisting in the first place of obtaining the steel of a piping composition, and in the second place of arranging for a fluid reservoir of metal to fill up the cavity, was the most satisfactory, and it was certainly interesting to learn that the use of such carefully topped ingots for the production of rails was under contemplation in America. The ingots used for that purpose, as indicated by the authors, were cast under conditions differing so greatly from those under which high-class Sheffield steels were cast, that the technical difficulties of preventing pipe and blowholes had led the manufacturers to rely largely upon such defects being removed by the work done in rolling. It was noticed that Sir Robert Hadfield arranged for his ingots to be cast from the top, singly. Had he any experience of endeavouring to do away with the pipe when the ingots were cast from the bottom in bunches? To cast in bunches had, of course, several advantages from a works point of view, but having in view the fact that the metal in the top of the ingot was generally the coldest, difficulty might be encountered in feeding the pipe thus produced. Casting the ingot as indicated in the paper, with the wider end upwards from the top, certainly provided the most successful conditions for preventing the occurrence of pipe.

The authors claimed that by casting in that manner segregation was reduced to a minimum, and their figures were interesting in that respect. On the face of it, it could hardly be expected that any method of casting would really counteract the tendency of steels to segregate, and if the authors or other workers would publish series of figures similar to those on pages 47–49, obtained from ingots of varying composition, size, and casting temperature, the results would be invaluable. Obviously, if the pipe were prevented, the carrying of the richer segregate into the body of the ingot would be also prevented, but there would probably remain, in large ingots at any rate, a segregation of sufficient magnitude not to be overlooked.

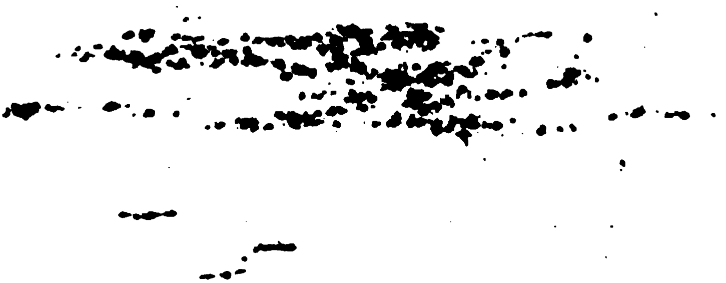
Mr. T. **Rowlands** (Sheffield) wrote that, from his own experience, when dealing with heavy (5 to 10 cwts.) crucible steel ingots, he had proved the value of casting with large end up, covering the molten metal in the fireclay head with charcoal and later feeding with the same class of steel. Sir Robert Hadfield went further than that with his process, which would give very much better results at a low additional cost to the plant. The amount of aluminium added to the molten metal, 2½ lbs. per ton, seemed to be excessive, and as it was generally conceded that alumina, which might be trapped in the steel, was very undesirable, the advisability of that addition might be queried, but if the elimination of the alumina could be assured, the objection was removed. He wished to ask Sir Robert Hadfield if he had applied his process to steels treated with other deoxidisers such as titanium, in place of aluminium, as he considered that if the danger of included alumina were removed, engineers generally would welcome the extra security just as much as steel-makers ought to appreciate the economy produced by the process. The photomicrographs shown in Plate X., and for which he was indebted to Mr. G. F. Comstock, showed characteristic alumina inclusions and a view of some streaks of alumina which had caused the top of the head of a rail to shell off.

Mr. C. P. **Sandberg** wrote that Messrs. Sandberg had studied Sir Robert Hadfield's paper with very great interest, and congratulated him on bringing into more prominent light the important question of obtaining solidity of steel ingots and freedom from segregation.

It was undoubtedly true—especially in the case of rails—that many failures could be directly attributed to the steel having been piped or seriously segregated, or a combination of both these defects. A practical, cheap and successful remedy for these evils would prove of great advantage, not only to the steel manufacturer but to the consumer, especially in view of the modern tendency to larger ingots and hard steel. If a satisfactory solution for the reduction of pipe and segregation could not be evolved, then it seemed to him that the advantage of a large ingot disappeared to a great extent in view of the necessary amount of discard.

If Sir Robert Hadfield's process could be applied at anywhere near the low cost mentioned by him, one might have every confidence that steel-makers would themselves see the advantage of applying the process on a large scale, as the extra cost would be more than repaid by obtaining a larger percentage of good steel, while obviously consumers or railways would very quickly appreciate steel free from pipes and segregation.

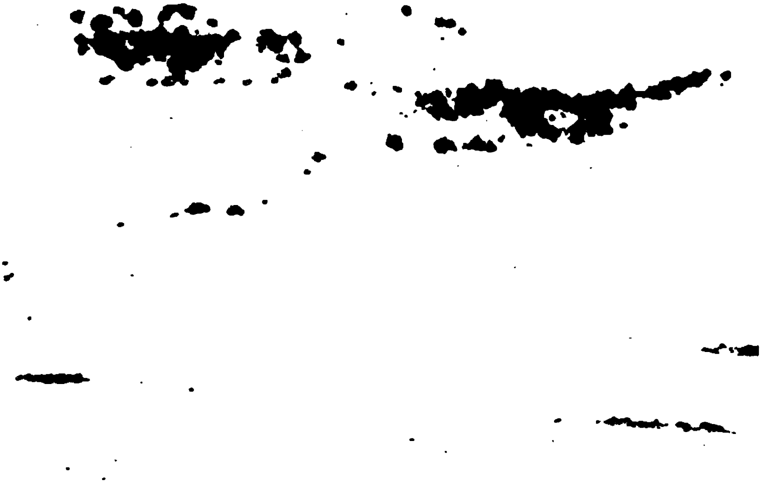
The results would have been even more interesting and more



No. 1.

Alumina inclusions in steel treated with large excess of aluminium. (The few grey spots are sulphides.) Polished section is parallel with direction of forging.

Magnified 200 diameters.



No. 2.

Alumina inclusions at the top and sulphides at the bottom, in a longitudinal section of the head of a rail which broke in service, and showed a streaked fracture.

Magnified 200 diameters.

comparable had the experiments been carried out on a large number of ingots at the same works, and if the steel had been manufactured by the same process, and were of the same chemical composition, the ingots being cast in the same manner, so that all conditions would have been identical, except for the application of the Hadfield process. No doubt further trials would be carried out on those lines with very interesting results.

From Messrs. Sandberg's own experience in testing and inspecting large quantities of rails and other steel materials, they had not found such a high proportion of unsoundness in the average make of ingots as mentioned in the paper, nevertheless, even if the figures might not be strictly correct, there was no doubt room for considerable improvement. In their opinion the remedy did not lie in specifying for a discard of 30, 40, or 50 per cent., as such methods were so uneconomical that it was not feasible to carry them out in practice. The remedy lay rather in improving the manufacture, and so reducing the amount of discard necessary, whether by the Hadfield or other process.

They had noted in testing large quantities of silicon steel rails that even where the remains of a pipe might appear in the tested crop end cut from the top end of the ingot, there was a remarkable tenacity, which might be attributed to the steel having been thoroughly deoxidised, and being extraordinarily free from segregation. Similar traces of piping in ordinary steel rails had been found sufficient to cause fracture at the tup test, even with less than the specified height of drop.

The subject to which Sir Robert Hadfield had given so much attention was one of the most important, not only to the steel manufacturer, but to railways, and, in fact, to all consumers of hard steel.

Mr. Ralph G. Scott (London) wrote that the members were much indebted to Sir Robert Hadfield and Mr. Burgess for the interesting account of a very complete series of tests carried out in a particularly careful manner, and representing an amount of work and thought most useful to workers in steel.

It was no doubt necessary to keep continually before the makers of steel ingots (for whatever purpose the steel was to be used afterwards) the paramount importance of starting with a sound ingot.

The authors showed a method of making sound ingots, and referred incidentally to the improvement produced by casting the larger end up. He (Mr. Scott) had not tried casting ingots in that way, but in studying the Harmet process at St. Etienne, he had noticed that when the pressing of ingots was stopped at various stages of the solidification of the steel, the last place to show porosity in an incompletely compressed ingot was near the bottom, *i.e.* the large end of the ingot.[1] Now that process had always seemed to him a perfectly natural method of making ingots absolutely sound, because the lateral pressure brought to bear on the solidifying steel in the mould was made to compensate exactly for the contraction of bulk which was taking place, and followed it *pari passu* until the ingot was solid from top to bottom.

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[1] *Journal of the Iron and Steel Institute*, 1902, No. II., Pl. VI.

The "feeding" of the ingot was done from the liquid portion, and, as the experiments proved that the last part of the ingot to remain liquid was near the large end, he presumed that the wonderful homogeneity of a Harmet ingot was due to the fact of its being fed from a part of the ingot where no segregation was taking place. He thought the above facts corroborated Sir R. Hadfield's contention, that when no outside pressure was used to help the consolidation of ingots, there was an advantage in casting them with the larger area at the top.

With regard to the ingot shown in Fig. 2, he (Mr. Scott) did not know whether the maker who supplied it agreed that "it represented the usual type used for steel rails." If so, there was no doubt that a drastic alteration should be made in the manufacture of the steel. As a matter of comparison it seems a pity that the authors had not shown a number of ingots made from the same cast of steel. He would suggest six altogether—two cast, for instance, in the ordinary way, two with a non-conducting top, and two with a fully equipped arrangement as proposed in the paper. If three of the ingots, made as suggested, had been cut up longitudinally and examined minutely, as had been done with Nos. 1 and 10 in the paper, and the three corresponding ingots had been rolled into rails and tested in various ways, there would have been obtained, with about the same amount of work, a much more valuable series of data to guide manufacturers in the search for improved methods of making sound ingots, and a definite indication of the advantage of using the process advocated by the authors. He hoped that at some future time such a true comparison of ordinary and improved practice might be given to the Institute.

Mr. T. M. **Service** (Glasgow) wrote that the results which Sir Robert obtained by his method were very satisfactory, and when the section of the ingot shown in Fig. 1 was compared with the section of the ingot shown in Fig. 2, the superiority of his method was realised at once. No objection to his ingot could be raised on the points of freedom from blowholes and pipes, but on the question of segregation, he (Mr. Service) thought there were still some points worthy of discussion, one of which was, Why did Sir Robert not make his ingots 1, 2, and 4 with pig iron which would give the same or almost the same percentage of sulphur and phosphorus as ingot No. 10? He (Mr. Service) rather feared that with that high percentage of phosphorus (0·09 per cent.), the uniform results shown in Figs. 4, 5, and 6 would not be obtained.

Ingots Nos. 8 and 9 had been inserted for comparison, but would not the comparison have been better if those ingots had been made of the same material as ingots Nos. 1, 2, and 4, and also if the same percentage of aluminium had been added to Nos. 8 and 9 as had been added to Nos. 1, 2, and 4? It seemed to him (Mr. Service) that if that method had been carried out, and either Nos. 8 or 9 ingots split and a sulphur print from them taken, it would have demonstrated quite clearly the difference between those two types of ingot. Would Sir Robert state whether the mould with narrow end down was simply the one with the wide end up, inverted?

Fig. 19, B, was not a satisfactory structure, and it would be interesting to know from what part of the ingot the piece from which the section was cut had been taken. That lamellar structure with inclusions, usually slag or manganese-sulphide, caused considerable trouble in special classes of material. Had Sir Robert never found that to be the case in ingots cast wide end up, and with additions of aluminium (0·1 per cent.)?

According to the evidence brought forward, it looked as if the mould with the wide end up, and feeding head on Hadfield's principle, were sufficient to produce satisfactory ingots. To him (Mr. Service) there appeared, however, still another factor in the equation, namely, the steel.

For instance, would Sir Robert expect to get similar results to No. 1 if he cast material Nos. 6 and 7 into his moulds, and fed the head by his process? Mr. Service doubted that, and he was doubtful what the process really was. He hoped Sir Robert would say whether it was: 1st, Liquid steel cast into mould with end up, having brick-lined head, the metal in head being covered with slag and coke, and air under pressure supplied to ignite coke, and keep metal in head fluid? or 2nd, Was it No. 1 with the addition of aluminium (0·1 per cent.)? If it was No 2, would Sir Robert Hadfield state whether that aluminium was added to the ladle, and, if so, did he not find that a very high temperature was necessary owing to the fact that the aluminium made the metal pasty?

In Fig. 8, fractures Nos. 2 and 8, there was distinct evidence of piping. As those fractures were taken at the bottom end of a top-rail, which was approximately 25 per cent. of the body, was No. 2 exceptional? or when only a cropping of only 10 per cent. was considered necessary, was there any other evidence of piping or sponginess in the remainder of the metal which he considered good quality?

Dr. J. E. **Stead**, Vice-President, wrote that the proof appeared to be complete that by the method described by the authors, sound ingots could be regularly obtained. Sir Robert Hadfield had given him (Dr. Stead) other evidence privately emphasizing that important fact. Not only small but large ingots could be produced free from pipe and honeycomb. The fact that the "discard" could be reduced to 9 or 10 per cent., leaving about 90 per cent. of perfectly sound steel, should appeal to everyone.

Why should not the method be applied to the production of armour-plate and big guns? If the same results could be obtained in making such ingots as were obtained in making those of smaller size, compression in the mould would be unnecessary. It was difficult to explain why there should be parts in the central axis of No. 8 ingot specially fed, which were very low in sulphur, phosphorus, and carbon. There could be no doubt, however, that these consisted mainly of primary crystallites, which were always relatively much purer than the average of the whole mass of steel. The ingots were presumably not compressed when the central axes were in a semi-fluid condition, but whether the remaining liquid was, after the pure primaries had solidified, removed by pressure or liquation it nevertheless was removed. The only explanation that appeared tenable was that the liquid in the central axes, just before complete solidification, when the primaries formed bridges from side to side of the solid walls, sank downwards leaving slightly spongy centres of the primaries. On rolling the ingots, those pure primaries would be perfectly welded together, and would be drawn out, appearing in the finished rails as white streaks. That such phenomena did occur sometimes in the case of high carbon steels had been proved, for the central axes of a spongy character in steel ingots had been noticed containing only 0·9 per cent. carbon, while the outer parts contained 1·2 per cent. There could be no doubt that for rails, sound ingots were to be preferred free from pipe, but it should not be inferred that honeycombed ingots did not make good and safe rails, for it was rare that loss of life on English railways occurred, although most of the rails were made from ingots more or less honeycombed.

Messrs. R. Wight-Boycott and A. Colley (Bilston) wrote saying they had visited the Hadfield works to see in operation the system described in the paper. They saw the following cast made:—

At 4.30 p.m. a charge was tapped from a 15-ton Siemens' open-hearth acid furnace. About fifteen minutes before tapping ferro-silicon (25 per cent. silicon) was added to the bath, and about 2 lbs. of aluminium (that is for 15 tons) were added to the ladle whilst tapping.

The casting-pit was at right angles to the furnace, and held 22 ingot moulds, with a 20-ton ladle with carriage support running on rails the length of the pit, and operated in their usual way.

The ingots were cast with the wide end uppermost, and on the top of each mould was stood a cast-iron box lined with moulding composition and with an aperture of about 6 inches diameter. Methods had also been introduced for boxes with a firebrick mould and rammed with foundry sand, those lasting no less than thirty heats, that was to say, for thirty separate ingots without renewal except occasional patching.

Each ingot was filled up to within about two inches of the top of the sink-head box. A man then added two gills of cupola slag, broken down to the size of peas, and when that slag was quite fluid a half-shovelful of ordinary wood charcoal was thrown on, and a feeble blast taken from a pipe running the length of the pit by means of easily moved branch pipes was applied above the charcoal, maintaining a heat sufficient to keep the steel in the sink-head box liquid, which in its turn supplied the liquid steel to correct piping. In that way the segregated area was brought into the sink-head portion of the ingot. It took about twenty minutes to cast the heat, and when the last ingot was poured the blast was taken off the first ingot, then from the second, and so on, whilst it was noticed that a cavity had formed in the sink-head portion, showing that no less than about 80 to 100 lbs. of molten steel had sunk down into the body of the ingot. After the material had solidified the ingots were drawn and allowed to go quite cold.

A large number of ingots were shown laid out for inspection after being treated as follows:—

The ingot was placed in a lathe and 15 per cent. parted off the top end by means of a parting tool nearly to the centre, leaving about 8 inches solid diameter in the middle. The ingot was then taken out and broken through the partially parted portion by means of wedges driven into the cut, and placed for inspection of the fractured centre, and of the many ingots seen not one showed any trace of piping or defect whatsoever, which would appear to be a conclusive proof of the efficiency of the system as regards solidity, while its application appeared quite simple. The results as seen in the ingots laid out for inspection were surprising. The advantages gained by producing sound ingots of the description given, not to speak of the homogeneity of the material claimed as part of the result of the process, would be so obvious to practical steel-makers as to need no further remarks.

Mr. H. W. **Belnap** (Washington, U.S.A.) wrote that the deepest interest attached to those researches having for their object the improvement of metallurgical processes and products in which Sir Robert had taken so distinguished a part. The requirements demanded of steel which reached in its commercial state the form of a steel rail were of peculiar severity, and possibly no other steel product furnished a parallel example. Sir Robert truly remarked, on an earlier occasion, in defining an essential pre-requisite, that it was necessary to start right in order that the ultimate result should be what was desired. Starting right in the present instance was the production of sound steel in the ingot.

It was believed to represent the experience of steel-makers that a given degree of excellence had to be attained in the ingot to ensure proper results being arrived at in the final shapes into which the metal was worked. The subsequent working of the metal admitted of many modifications, but primitive inherent conditions exerted an influence on the final product which, were it a rail or structural shape of whatever kind, if detrimental, could not be effaced.

In the general conclusions the authors presented, interrogatively, the query whether it was not worth while to use only sound steel; and, assertively, the promise was held out that steel rails could be made so that every rail would be sound, and it was also added, that it would be safe. It would, of course, be understood that the proper use and limitations of the rail to suitable fibre stresses, when in service, would constitute a qualification in respect to the latter feature, that of safety.

The authors clearly took the position that 50 per cent. only of the piping ingot was of sufficient soundness to be available for rails, referring, it was to be understood, to the American comparison ingot, cast in the ordinary manner, according to current American practice. It was quite unnecessary to remark that in American mills no such amount of discard was being made, such as in the opinion of the authors seemed essential to secure steel of adequate soundness for the purpose, taking the ingot presented as a typical one. So great a discard obviously would be a serious economic feature to encounter, and its enforcement would no doubt meet with vigorous opposition, as tending materially to enhance the cost of that portion of the ingot which would be converted into rails. Nevertheless, the production of rails should be so conducted that unsuitable steel should not find its way into rails which were accepted for and put into service.

Specifications governing the acceptance of rails might require revision properly to ensure the acceptance of suitable rails and cause the rejection of those which were unsuitable. It was to be hoped that the authors would continue their researches in order that those vital features which were embodied in their paper might be brought to a completed state, involving a more comprehensive exposition of the subject.

The authors remarked that physical and chemical tests were not an adequate measure of the quality of steel rails, and that neither the tensile tests, the drop test, nor the chemical analysis could be depended on to separate the sound from all the unsound rails. In a matter of so great importance it was to be hoped that the authors would be enabled to offer, as the results of further study, some promising, tentative plans by means of which a proper discrimination might be made, and rails of adequate quality for meeting service conditions be initially judged of, so that only satisfactory rails should be permitted to be placed in the track. The service record of those rails which had been rolled from the ingots described by the authors, which were made from the modified method of ingot casting, would be looked forward to with very deep interest.

Mr. W. C. Cushing (Pittsburgh, Pa., U.S.A.) wrote that the paper was practically a supplement to Sir Robert Hadfield's communication to the Franklin Institute in February 1915, and mentioned in the bibliography as No. 8, "Sound Steel for Rails and Structural Purposes." The explanation of the apathy therein alleged to exist in America was to be found in the attitude of some manufacturers, that it was cheaper to make a large discard and eliminate the poor material, rather than save that material by spending the additional money necessary for the "sink-head" or "feeding" process. They did not accept the statement that money would be saved by feeding the ingot. That was surveying the problem from the monetary standpoint only, although the statement had been made that the large discard would produce just as good material as the "feeding" process. In view of that attitude of mind, the rail manufacturers of America, with some exceptions, were constantly urging the introduction in the rail specifications of an arbitrary discard clause of not less than 25 per cent.

That the railway engineers are as constantly resisting, believing as they did in the progressive discard as determined by inspection and analysis. To accomplish that, the Pennsylvania Railroad system had had several thousands of tons of rails rolled in accordance with their 1915 specifications. They were different from all other specifications in requiring the check analyses to be made from the finished rails instead of from the test ingot cast for the purpose when the ingots were being poured. In those check analyses, the difference between the amount of carbon at "O" and at "M," as stated in clause 6*d* (Fig. 7 also represented it), must not exceed 12 per cent., which was an arbitrary limit determined upon after an examination of the results of the laboratory survey of several hundred rails which had failed in service.

The rails rolled and examined in accordance with those specifications in the current year had shown that the same discard might not be necessary at all mills, and that in some cases much more than 25 per cent. would be required to secure sound material, perhaps even up to 40 per cent. and more.

He (Mr. Cushing) believed with the authors, however, that due consideration had not been given by the manufacturers, who advocated a large discard, to the fact that the lower part of the unfed ingot was not improved in quality by the large discard; only the poor top had been cut off; while in the case of the fed ingot, the whole ingot was improved.

That improved quality, if a fact, was in his (Mr. Cushing's) opinion the most important reason for adopting an improved method for casting ingots. That the "fed" ingot method was such an improved method had already been tried and proved by some rail manufacturers, and the trials in order to make the process a commercial success likewise were to be continued. In order to help in that object, the Pennsylvania Railroad Company, in consequence of the recommendation of its rail committee, had received 100 tons of ingots made in accordance with its order by the sink-head process by Hadfields, Ltd. They were at Sparrows Point, Maryland, and would be rolled into rails, sufficient portions being kept for thorough physical and chemical survey. They were to be higher in carbon, from 0·60 per cent. to 0·75 per cent., than the ingots mentioned in the paper.

The two most serious defects found in the finished rails, other than those introduced by the operations of heating, blooming, and rolling, were:—

(*a*) The so-called "transverse fissure,"
(*b*) The surface cracks,
and it was absolutely as necessary to conquer them as to have sound steel. He (Mr. Cushing) was not certain that they would not be found in the Hadfield ingots.

(*a*) The "transverse fissures" mentioned by the authors were being studied by many metallurgists and engineer physicists, in order to determine their cause. Mr. Wickhorst's latest study was to be incorporated in *Proceedings of the American Railway Engineering Association.*[1] Mr. Jas. E. Howard (Engineer Physicist of the Interstate Commerce Commission) had come to the conclusion that high-wheel loads and hard steels were vital features in the formation and development of such fissures, and had so stated in several public reports of accidents, the latest being on one near Alford, Pa., on 31st October 1914. It could hardly be disputed that service conditions develop cracks and fissures, but reducing the severity of service was not the way to cure a defect. Mr. Wickhorst's investigation showed that the incipient cracks existed in some rails which had not been in service, and had not been straightened in the press, that was, gagged. Mr. Young's investigation[2] showed in nearly all cases the presence of slag. (See Plate XX.)

With all the constant demands bringing about increased cost of operation on the one hand, and reduced revenue on the other, it was not constructive work to advocate smaller wheel loads, as it was not attacking the evil at its source. A reduction of unit stress in the rail should come in another way. In the meantime, it was necessary to continue the efforts to find out the true cause of transverse fissures, and eradicate it. If the "fed" ingot would help to bring that about, so much the more reason for introducing it universally into rail manufacture.

(*b*) Another serious defect was the surface crack, which, when in the base, seemed to cause the failure known as "broken base," and often led to broken rails and other failures. Mr. Wickhorst[3] had also investigated that trouble for the rail committee of the American Railway Engineering Association, and had shown that some of the cracks or tears made during the blooming process were not later removed by welding in the subsequent rolls. The ingot might be sound to start with, but those defects might be introduced by the subsequent operations. The railway engineers were, therefore, endeavouring to have those practices improved. The Lackawanna Steel Company had accepted the cracks as necessary "and beyond the control of the manufacturer," and then proceeded to remove them by the "Mathias Deseaming Process," recently described in a brochure issued by that company. That was accomplished by introducing a machine with a rapidly rotating cutter at the point where the hot rail bar was approximately 75 per cent. finished—that was, after the ingot had been bloomed to an 8-inch by 8-inch cross section, after the end had been cropped and the bloom further reduced by five passes, more or less, in the roughing or shaping stand of rolls. The machine was set to remove from the top and bottom surfaces about $\frac{1}{8}$ inch of metal, or at the extreme $\frac{3}{16}$ inch, and consisted of two opposed rapidly rotating saw discs with broad teeth, wider than the rail-bar section.

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[1] Vol. xvi., year 1915.

[2] *Proceedings of the American Railway Engineering Association*, 1913, vol. xiv. p. 422.

[3] *Ibid.*, 1914, vol. xv. p. 315.

That again was temporising with the effect, and not preventing the original cause, which seemed to be the wrong principle. There were thus several defects in rail manufacture, only one of which was the poor ingot, but as that was the foundation for the subsequent work, it was of the first importance to make it good, and the authors deserved the thanks of the railway engineers for the results of their studies as outlined in the report. Sir Robert Hadfield's persistency in continuing the agitation for sound ingots placed rail users under a deep obligation. It was needful likewise to keep in mind the necessity for progressive improvement in the rolling-mill, and for constant effort to discover and eliminate the cause of transverse fissures.

Dr. P. H. **Dudley** (New York) wrote that the subject was one of importance, and extensive studies had been made in the United States for the past quarter of a century upon sound steel ingots, and the subsequent rolling and finishing of sound steel rails.

The experience of the introduction of stiffer and heavier rails, and the consequent increase of wheel loads and weight of trains in the past two decades in the United States, had required not only the study of the ingots and sections, but of the entire fabrication of the rails as a finished product from the mills. That was particularly the case since the exhaustion of the low phosphorus ores in the United States and the substitution of basic open-hearth rails for the 0·10 phosphorus Bessemer output.

The authors stated their indebtedness to Mr. Wood, President of the Maryland Steel Company, in terms which showed that the Maryland Steel Company co-operated, and were not remiss in their assistance, in making the rolling of the rails a success. It was difficult, therefore, to understand the academic statements in reference to the superior quality of the ingots cast by the feeding methods, which produced in rolling so many rails rejected as firsts and classed as seconds. The latter would not be permitted in main track service of first-class roads in the United States, and consequently would represent a large economic loss to the consumer buying such ingots and expecting that they would produce first quality rails for a supposed increase of safety as compared to the present manufacture of American rails.

Railroad officials who are responsible for the manufacture of rails and their use, were studying the unusual percentage of seconds compared to the firsts, and were inquiring what was the matter with the rolling of the steel in these three ingots cast by the feeding of the top, that it should produce such a large percentage of second quality rails, as shown in Table II.—"Rolling and Inspection of Ingots and Rails," p. 53. It stated in the column for the number of the ingot and the percentage of the ingot available for rails that for No. 3 ingot there was 91·5 per cent. available for rails, of which the firsts were 77·2 per cent. and seconds 22·8 per cent. Ingot No. 2 the percentage available for rails was 89·9 per cent., firsts 77·1 per cent., seconds 22·9 per cent. Ingot No. 4 available for rails, 88·4 per cent., of which 52·5 per cent. were firsts and 47·5 per cent. seconds. The statistics of the percentages of the firsts and seconds, furnished by the paper, were the results obtained in rolling and classified by the railroad inspector receiving the rails, who designates his firsts and seconds primarily from the fact that the firsts must be without visible exterior surface checks or seams, while the seconds were rejected as firsts owing to such defects having developed in rolling the steel.

It was well known that the Maryland Steel Company rolled the product of their own ingots under a small percentage of seconds. The Company's output was generally less than 5 per cent. of seconds, and oftentimes it was even less than 2 per cent., showing that they were able to roll and finish their product without such high percentages of seconds as occurred in the three Hadfield ingots designated in Table II. There were American mills now rolling sound basic open-hearth rails in heavy sections with less than 2 per cent. of seconds every day. The specifications for the manufacture of rails for the railroad companies in the United States generally provided for the acceptance of 5 per cent. of seconds. Any produced over that amount were not purchased. The excess seconds of 17·8 per cent. over the 5 per cent. accepted in the United States for ingot No. 3, 17·9 per cent. for ingot No. 2, and 42·5 per cent. for ingot No. 4, were exceptional amounts for the supposed high-grade ingots, and would require a larger tonnage than originally expected to roll the given quantity of first quality rails, therefore greater cost.

The actual rolling results did not coincide with the statements of paragraphs Nos. 4 and 5 on page 41, and discrepancies of that character made experienced railroad men doubtful about a method which claimed to result in greater economy and safety until it had been determined by manufacture and service tests.

The cold cut Hadfield ingot "cast by the feeding method," was compared with an ingot, No. 10, made by American practice. To cut the American ingot it was allowed to become cold, and consequently all of the exterior shrinkage from the dimensions of the ingot in the mould, and the interior or minor shrinkage of the steel had taken place from the hot set metal to that of the cold metal. The practice of allowing the rail ingots to cool down before blooming had not been either English, French, or American practice for the past four or five decades.

The question of the volume of the exterior or major shrinkage of the ingot, and the interior or minor shrinkage cavity for different weights and shapes, had been studied, and by promptly charging the red hot ingots of proper base area compared to height into re-heating furnaces, the major shrinkage cavity of the hot set metal was small, and the interior or minor shrinkage was but a trace before the ingots were bloomed, and was removed by the 9 per cent. discard from the top of the ingot.

It had been his (Dr. Dudley's) custom to find out the percentage of the interior shrinkage cavity compared to that of the cold cut ingot, to split the top discard of the bloom from a companion ingot which was charged promptly into the furnace and rolled, and then to compare the trace of a shrinkage cavity with that formed in the cold cut ingot from the same melt of steel.

Ingots 20 × 24 inches and 68 inches high, average weight 8300 lbs., one in plain steel, the interior or minor shrinkage cavity was 469 cubic inches. A second ingot of the same size and weight was treated with 0·1 per cent. of metallic titanium to check the segregation, and the interior shrinkage cavity was 369 cubic inches, while the 9 per cent. discard for the top of the bloom, it was less than 2 cubic inches in the plain steel, and still less in the treated ingot. The deoxidisers had to be adjusted to make rail steel which would set solid in the ingots under good conditions of manufacture. He (Dr. Dudley) had done that when he commenced to make rails in 1891. He had in the past twenty-five years made or had the responsibility of making nearly 2,000,000 tons of rails. Commencing in 1891, he made over 500,000 tons of Bessemer rails to 1898, in which the phosphorus content did not exceed 0·06, while the carbon content was from 0·50 to 0·65, being graded for the different weights of sections of rails into which the Bessemer metal was rolled. There were several thousand tons of the rails he made in 1891–2–3–4, in the $5\frac{1}{8}$-inch 80-lb., $5\frac{1}{32}$-inch 95-lb., and 6-inch 100-lb. sections, still in service, and but few breakages of rails from those ingots had since occurred. Had the ingots been of the character which Sir Robert Hadfield said "they probably were," there would have been many breakages instead of a few.

The New York Central and Hudson River Railroad, to lay its two tracks forming a four-track railroad from Albany to Buffalo, 300 miles, bought in 1869–70 many thousand tons of steel rails made by John Brown & Company and other English manufacturers at Sheffield. He (Dr. Dudley) had had the opportunity of running over those rails with his track indicator for many years, and, while they became outclassed, they were not worn out in the sense of abrasion of the metal from the rail head. Those rails did not fail by breaking due to piped ingots or unsoundness of the steel, but were finally removed from the track for the reason that they were outclassed for the increasing wheel loads. They cost from $100·00 to $110·00 per ton, and were good, not bad rails, as might be inferred from the paper under discussion.

During the extreme cold winter of 1912 there were 51,700 tons of 5⅛-inch 80-lb. rails, or 406 miles of track of the rails made from 1891 to 1899 of 0·06 phosphorus and 0·56 to 0·60 carbon. There were only ten broken rails—and none of these were from piped ingots—for all that mileage under the heavy traffic of the New York Central and Hudson River Railroad at that date. The broken rails were square breaks, and the fractures in some instances could be traced back to the locked up strains of gagging in straightening the rails when manufactured. During the cold waves in January, February, and March 1912, when those rails were in service, the temperature would often fall to 20 and 30 degrees Fahr. below zero, which would decidedly shorten the duration strain factor of the metal under the moving equipment. In the case of rails rolled in 1904–5–6–7, in which aluminium was used in the top of the ingots to quiet the steel, particularly for the years 1904–1905, many of the ingots had pocket pipes, and the breakages of those rails were greater in proportion to the tonnage than for those made in the earlier years mentioned.

He (Dr. Dudley) was Reporter for the International Railway Congress at the Sixth Session at Paris in 1900, and in his report included diagrams of the temperatures from Greenwich Observatory, England, New York and Albany for the United States, and St. Petersburg, Russia, showing that it was necessary in cold countries to take into consideration questions in respect to breakages of rails that in the mild climate of England would not have to be studied. The rails laid in the tracks in the northern latitudes of the United States were often subjected in the summer-time to a temperature of 110° to 120° in the sunshine during July and August. The same rails in the winter-time would often be subjected to temperatures 40° F. below zero. That made a range of 150° to 160° of temperature which had to be considered in laying and spacing the rails, also the stresses due to the tension before they had fully rendered in the splice bars for contraction in the falling temperatures. The winters were not uniform: some were more severe in their cold waves. The temperatures of the United States Weather Bureau stations upon the New York Central lines showed that in the year 1911 there was an accumulated excess of temperature at nearly all of the stations for the vast extent of territory occupied by the New York Central lines. When those excess temperatures occurred, the following winters would be very much colder than usual for the mean temperatures closely balanced from year to year, though there were cycles of cold waves which extended through five to ten years. The year 1911 had accumulated plus or excess temperatures for each month. December was abnormally mild, except for the last one or two days. The rails had contracted during November in the lower than normal temperatures, but expanded again in December, and the severe cold wave of 20° to 30° below zero of January 1912 induced unusual tensile stresses in the rails before they could render in the splice bars. These, combined with the stresses in the rails under ordinary traffic, caused the greatest number of broken Bessemer rails on the lines of the Northern railways in their history. The railways in Minnesota for the first three weeks of January 1912 averaged more than one broken rail per mile without a serious accident to the trains. The Report of the Rail Committee of the American Railway Association for the year ending October 31, 1911, showed: for 12,688,714 tons of rails laid, 36,642 failures; and to October 31, 1912, for 13,736,956 tons, 61,047 failures. That number would have been only 39,688 under the ratio of the mild winter of 1911, while 1912 was intensely cold, the effects of which lessened the duration strain factor of the metal with a *pro rata* increase of 21,379 failures, quite independent of defective ingots.

The year 1912 had accumulated minus or deficiency temperatures for each station fully reported, except New York and Boston, followed by the mild winter of 1913 with many less broken rails and shelled wheels. The accumulated excess or deficiency temperatures for the New York Central lines were sent to the Operating, Motive Power, and Maintenance of Way Departments with a forecast of the probable severity of the winter season, advising the latest dates for the wheels of the equipment and the track to be up to their highest standard for the winter season.

Great Britain, in its higher latitudes than the United States, was warmed in the winter by the waters of the Gulf Stream, and the temperatures hardly fell to zero, and part of the time was not much below freezing, except in the northern part of Scotland. The temperatures in the summer were decidedly lower than in the United States. There was also another feature which was important, and that was the low rates for carrying freight, which could only be met by heavy wheel loads and long trains. The axle loads under the locomotives were heavier than in Great Britain, which, with the climatic conditions, made railroad operation more difficult and severe than occurred in England. It would be necessary for Sir Robert Hadfield to convince many of his American friends, manufacturers and consumers, that he had suggested the full remedy for broken rails which occurred in America. He made one observation, which was true, that the severity of the climate for the "Northern lines" was more severe than in England, also that the wheel loads were heavier, While that was true, Dr. Dudley wished to call his attention to the fact that the differences in the severity of the winters had quite as much to do with the breakages of rails made from sound steel, and even were they rolled from Hadfield ingots, the fractures would not be materially reduced.

The question of sound steel rails was no longer an academic question, for there were ample experiments to show that millions and millions of tons of rails, manufactured either in England, France, or the United States had been worn out without breakages, showing that the ingots were sounder and better than indicated by the sample of a cut ingot with its interior shrinkage cavity, as exhibited in Fig. 10, for the interior shrinkage cavity, by proper knowledge and efficient care in manufacture, was not allowed to form. He (Dr. Dudley) wished to state emphatically that the cold cut ingot was not a correct representation of his practice of making rails from large ingots. Sir Robert Hadfield spoke of the interior transverse fissures, and stated that most of them occurred in the "A" rails, and with his top fed ingots, the segregation being reduced, the interior transverse fissure would be practically remedied. The percentage of interior transverse fissures was slightly greater in the A and B rails from the records obtained to date, but they were also numerous in the C and particularly in the D rails, and in case E and F rails were rolled from large ingots, they were also found in those.

The interior transverse fissures were only found so far in the open-hearth rails where the transformations from the hot molten metal were not entirely complete in the central core of the head. The statistics showed, particularly on the New York Central, that rails in which interior transverse fissures developed were rolled when the atmospheric and rolling temperatures were comparatively low, and the heat was extracted by the roll pressures in the rolling so rapidly that the transformations were not normally complete in the central core of the rail head, and the rails, before and during recalescence upon the hot beds, were subjected to gusts of cold air. The hot beds were now enclosed to a greater extent than was necessary for the Bessemer rails, and for the railroads to adopt the Hadfield ingots with the expectation that all the interior transverse fissures would be overcome, was not coincident with the experience and knowledge of the making of basic open-hearth rails which would be suitable for heavy service and the severe climatic conditions of the United States. In Sir Robert Hadfield's basic open-hearth steel ingots, with all their soundness and solidity, the transformations of the metal in the central core of the head could be delayed in the rolling, so that interior transverse fissures might develop in the track in some of those rails. It showed that the entire manufacture of rails, including the making of ingots and their heating and cooling upon the hot beds, must be considered before all the faulty rails would be excluded in manufacture. The question was much larger than the simply manufacturing one of sound ingots. That of itself did not of necessity insure that rails from those ingots would be metallographically sound unless rolled at proper temperatures, irregular cooling upon the hot beds being avoided, and straightening effected without injury. To complete the delayed transformations of the metal in the central portion in the rail heads when the rails left the hot beds low, the base required to be shortened and the head lengthened by just as many permanent sets in the head and base as it required to reduce the long curve by a series of short curves, which made the rail practically straight. A low rail which contained a central core of non-ductile metal in the head due to incomplete transformations, might be checked in the gagging upon the base, producing the intergranular nucleus from which an interior transverse fissure would develop in service under the strains of the passing wheel loads.

The high rail from the hot bed with a central core of non-ductile metal in the head, and the application of the gag upon the head had a tendency to uncap the metal of lesser ductility in the central core, producing an interior longitudinal check. The movement of the wheels over the heads of the rails finally enlarged the area of the separated metal, and a crack developed transversely in the head of the rail might work out to the gage side of the head. That type of interior transverse fissure developed from that crack as the nucleus through the metal above and below it. The proper reduction in the vertical curve in the rails would be to give each inch a certain amount of elongation in the member which required it, and also shorten the opposite member in both high and low rails. The permanent set required for that small amount would then be distributed nearly for the entire length of the rail, and with the probability that a number of those rails, even with the core of delayed transformations in the head, would not be injured or checked.

The entire methods of making the rails out of the basic open-hearth steels should be carefully considered in every stage of manufacture which would meet the conditions of traffic without failures. He (Dr. Dudley) knew from the excellent results obtained by the introduction of the basic open-hearth rails upon the New York Central lines, particularly upon the New York Central Railroad, that the fractures of the rails, exclusive of interior transverse fissures, compared with 0·10 Bessemer, had been reduced in about the proportion of 1 to 22 of Bessemer rails. It was evident now from the knowledge, experience, and service of rails, that in their manufacture, besides making sound ingots, efforts had to be made to roll the rails at the proper temperature and distribute them on the hot beds, so that the normal transformations in the heads would be completed during the separate recalescence of the base, followed by that of the head, for any section which had been so far designed. That meant expensive reconstruction in some cases, and the comprehensive subject of making sound rails was being studied by more users of rails and manufacturers than ever before in the history of rail-making.

Methods for more efficient straightening, without so much damage to the rails by gagging, had been considered thoroughly in the comprehensive study of rail fabrication, for it was evident that that would be necessary in any type of ingot produced. Many of the interior transverse fissures had developed in metal which was sound so far as the ingot was concerned, but the transformation of the metal from austenite through sorbite to pearlite did not fully complete itself in a central core in the head during the ordinary recalescence of the rails upon the hot beds. There were a sufficient number of consumers and manufacturers who understood those questions so thoroughly from the unexpected development of the fissures in the rails through the ordinary methods of manufacture, that they would not be satisfied with improvements in the ingots only, without including the measures necessary to cool the rails properly on the hot beds and to relieve the product of the injuries which occurred to the rails under the present methods of straightening them.

Mr. HENRY D. HIBBARD (Plainfield, N.J., U.S.A.) wrote that the paper furnished further valuable evidence of the fact that sound, pipeless ingots of staple grades of steel could be and were made commercially. Of course no mould or treatment in the moulds would make good steel out of bad. The metal had to be right chemically and physically before and during teeming. That meant that the ultimate and proximate compositions, soluble and insoluble impurities, quantity and compositions of the contained gases and means for controlling them, temperature of the metal, casting conditions and methods, had all to be suitable.

The ordinary ingot shown in section in Fig. 2 was better than the usual run of rail ingots, because almost any of the latter contained a series of skin holes in the upper end. Those were elongated gas-holes with their axes normal to the cooling surface and their outer ends not far from it. Those holes are particularly prone to become oxidised within during the heating operation, and to form seams in the finished rolled bar. The top of that ingot showed that the metal did not rise after teeming, but settled slightly, and outwardly it was a good sound ingot. Though the silicon in that ingot was not given with the analysis, it probably contained a substantial amount.

Segregation was a defect peculiar to most steels made by an oxidation process—that was, by the pneumatic converter or open-hearth furnace. It was unknown in crucible steels.

It seemed at first plausible to claim that the larger sizes of the ingots usually made by the oxidation processes would account for the segregation. The more slowly the steel solidified, the more pronounced its segregation in a general way. But as crucible steel was practically all made so that it would settle and pipe, if allowed to, in freezing, it suggested that the quality of the steel had much to do with segregation. That was borne out by oxidation steels to which enough silicon, aluminium, or titanium had been added to make them sound and piping, in which case segregation had been found to be largely prevented.

The remark, therefore, on page 46, to the effect that segregation was to be expected because of pronounced pipe was perhaps hardly justified. Segregation was to be suspected rather from the presence of gas-holes in the ingot. That apparent connection between or common cause of gas-holes and segregation needed to be explained. It would be well if it were stated in the paper how much time was required by the different ingots to solidify, or how soon after casting they might be put in the heating furnace or soaking pit. That had an important bearing on the production of rails or other staple steel goods which had to be made in an uninterrupted stream of output to satisfy the commercial requirements.

Professor **Henry M. Howe** (Columbia University, New York) wrote as follows: On page 42 it is said, "Inspection indicates that a discard of 50 per cent. would be necessary for the ordinary ingot." This seems to require some explanation. A discard of a little over 20 per cent. would have removed all the metal containing more than 0·104 phosphorus, and the remaining nearly 80 per cent. would have had no metal with more than 0·096 per cent. except for a rather short distance along its axis, where it rises to 0·104 per cent. With an average phosphorus content of 0·09, an enrichment in the very axis up to 0·104 certainly is not serious.

An examination of the segregation indicates that the advantage of the Hadfield casting is not in a reduction of the degree of segregation but in confining segregation to the very top of the ingot, as is natural. For instance, the greatest Hadfield enrichment in carbon in Fig. 4 is from 0·59 to 0·79, a gain of 0·20, or 34 per cent. The enrichment in carbon of the comparison ingot is from 0·46 to 0·59, a gain of 0·13, or 28 per cent. There is, however, this difference, that the Hadfield 0·79 is confined to about 5 per cent. of the upper part of the ingot, whereas the 0·59 of the comparison ingot is somewhere about 15 per cent. from the top.

The hardness numbers in Table III. are not so favourable to the Hadfield metal as might have been hoped. The A rail of the No. 3 ingot has a greater average deviation than any of the rails with which it is compared, and the next greatest deviation comes in the Hadfield A4 rail, 10 per cent.

A result of interest is the comparison of the piping steel, No. 6, and the rising steel, No. 7, in Tables III. and IV. The piping steel has a smaller deviation in hardness than the rising, and a much smaller deviation in carbon content, namely, 0·528 to 0·584, or 0·056, whereas the rising steel has a deviation from 0·550 to 0·648, or 0·098, nearly twice as much. If the authors could give some idea of how important a proportion of the breakages of steel rails is due to the kinds of defects which the Hadfield system aims at preventing, it would add very greatly to the value of their paper. In any event it is one to be welcomed as an important contribution to the knowledge on this important subject.

Mr. **Robert Job** (Montreal, Canada) wrote that the need for soundness in steel with freedom from segregation had been fully recognised for a long time, but particularly during the past decade or so, owing to the rapid increase in the severity of service conditions in most lines of industry during that period, and the Hadfield process for producing sound ingots seemed to be a most promising advance toward the practical production of safer and more serviceable steel. Many of the failures of important articles of steel had been caused by the presence of blowholes, and hence of porosity. That condition, as well known, could be largely remedied by use of "piping steel"—steel which could be made reasonably sound except for the central pipe, while the sink-head method of feeding castings to secure solidity and freedom from piping was a matter of successful daily routine in metallurgical work. The principle of the Hadfield process was thus correct, and the logical outcome would be increased solidity of the steel with freedom from piping, and consequent increase in the percentage of the ingot available for use—assuming that the composition of the steel and the mill operations were properly regulated. Steel of that character should be of decidedly better quality than that obtained by the usual mill methods.

In the United States under present conditions of railway service, it was especially necessary to secure sound serviceable materials, and great thought and effort had been given, both in developing suitable standards of quality and also in determining methods of test which would detect unsatisfactory properties when present. As a pertinent instance of such work, reference might be made to the inspection of steel rails, and it might be of interest to describe briefly some work carried out upon the Lehigh Valley Railroad in the effort to avoid acceptance of unsound and unserviceable rails. Previous study of the subject for many years, and of the various types of failures and their causes, had shown that as a rule failures in service were not characteristic of a rolling or of even a heat of steel, whether Bessemer or basic open-hearth, but that they were generally scattered irregularly throughout the heat. There was then devised and put into effect in 1911, for the first time in the United States, a more complete system of rail inspection, under which plan inspectors were stationed at various important parts of the mill, in order to see that good practice was observed, and that the requirements of the specifications were complied with. Each rail was stamped with the number of the ingot in addition to that of the heat, and the letter showing the location of the rail in the ingot. As a result of these studies, it was found that defective quality was occasionally characteristic of an entire ingot or even of several ingots, but that usually only an occasional rail in an ingot was defective, generally the top rail.

Under the method of inspection then in use six test-butts were taken at random from top rails to represent a heat of open-hearth steel. That gave fair assurance as to the general quality of the heat, but could not be expected to detect occasional defective rails which were liable to cause trouble, and, after thorough study of the results, it was decided that an all-ingot system of test was the logically correct method of inspection. In 1912 there was developed a plan under which a test-butt from the top of each ingot in each heat was tested under the drop, both for brittleness and for evidence of piping, and to measure the ductility. The first rollings under that plan took place in 1912, and a considerable tonnage had since been rolled under the system: the present practice being, in case of failure of the test-butt, to reject only the top rail of that ingot, and to make another test upon the back end of the top rail. In case of failure of that second test, all rails in the ingot were rejected. An entire heat was never rejected unless 50 per cent. or more of the ingots were rejected, in which case it was reasonable to assume that a radically defective condition was inherent in the heat.

The general working of the all-ingot system had been found very satisfactory. The number of rejections had been brought to a minimum, and instead of arbitrarily rejecting good material with the bad, as was necessarily done under the ordinary inspection system, it had been possible, with far greater certainty, to detect and to reject from a rolling the relatively few individual rails which would be likely to give defective service. The number of drop tests was necessarily largely increased, but with a suitable corps of inspectors it was possible to keep ahead of the mill without the slightest difficulty. The plan was satisfactory from the view-point of the mill, because it permitted the use of a greater percentage of the rolling than would otherwise be probable, and that gain was made without interfering in any way with the operation of the mill.

The development of the type of failure known as "Internal Transverse Fissure" in rails had been of importance in recent years, and had been carefully studied. As mentioned by him (Mr. Job) in a paper to which the authors had been kind enough to refer, that type of defect was investigated by Dormus in Austria over fifteen years ago, and was found to occur only in unsound steel, the carbon content ranging from 0·20 to 0·40 per cent in the steel at that time, and that general conclusion had since been borne out by his (Mr. Job's) own investigations. He realised fully the advantage to be derived from the use of sound steel, and welcomed developments in manufacture which tended to make its general use practicable.

Mr. **William H. Sellew** (Detroit, Michigan) wrote that the paper presented special interest on account of the increasingly heavy wheel loads being used, which made the rail problem in America an important one. That had been commented upon in the paper, in reference to Mr. Belnap's statement of rail failures. It should be observed that the statistics mentioned by Mr. Belnap probably included the 250,000 miles of main line in the United States, and also that during the period from November 1911 to January 1912 exceptionally severe weather was experienced by the roads in the Northern States, resulting in an abnormal amount of rail failures. During that period of very low temperature a great deal of trouble was caused by defective wheels, and on one road 400 rails, which had been damaged by a flat wheel on a dining car, were removed at one time.

It would seem that sound steel was especially desirable for rails on account of the selective action of the stress in the tread of the rail, which was highly localised at the area of contact of the wheel. This stress was considerable, and while it was true that the steel was in a condition approaching cubical compression, and could therefore withstand a high stress without injurious strain, still, if unsound metal were present, that may break down and cause a starting-point for a complete failure of the rail under a subsequent bending stress. The effort to make the rail hard enough to resist that stress had not been altogether successful in the standard sections, owing to the lack of ductility in the very hard rails, which resulted in more broken rails.

Some very heavy rails had been tried experimentally in the last few years, probably on account of the high carbon possible to use in the larger sections. In the 135 lb. section on the Central Railroad of New Jersey, about 6000 tons of which are in the track, the carbon varied from 0·90 to 1·05 per cent., a carbon content that obviously would be found undesirable in the 100 lb. rail.

What had caused so much anxiety in the past was the irregular failure of some of the rails, originating in defective metal. That was not necessarily in all cases primarily the fault of the manufacturer, as on account of the peculiar character of the stress in the tread of the rail, a more uniform grade of material was required than was customary in most other engineering structures where the stress was distributed over the entire cross section.

Some students thought that the wheel loads in use in the States had exceeded or were at least dangerously approaching the safe loading of the rails. The loads were without question very high, and the resulting stresses both from their amount and character called for a very high grade of metal in the rail. Steel having special properties had so far not been very successful, and it might well be that the sound steel obtained by the use of Sir Robert's process, together with a modification of the section to produce a better distribution of stress, would furnish the necessary relief.

SIR R. A. HADFIELD'S REPLY TO DISCUSSION AND CORRESPONDENCE.

Reply to Mr. Talbot.—It is somewhat difficult to answer Mr. Talbot's many points, for in some cases he appears to challenge statements that exist only in his imagination. For example, he said, "The eight other ingots were of acid open-hearth steel, made under the well known and expensive Sheffield system." As a matter of fact the ingots were made from converter steel, the charges being composed of Bessemer hæmatite pig iron. If Mr. Talbot had carefully read that and the previous papers by the authors, he would have seen that the American rail ingot taken for comparison was from the ordinary supply of acid Bessemer steel ingots. The silicon percentage was 0·11. That ingot was submitted to the authors as representing average American rail practice. On the other hand, if the ingot had been basic steel there did not seem to be very much point in Mr. Talbot's remarks under that head, seeing that rails from basic open-hearth ingots in America had broken almost as badly as those from Bessemer practice.

Objection was made to rail steel containing 0·2 per cent. of silicon. Many rails now made contained 0·3 per cent. of silicon, and they were all the better for that, the ingots being sounder. Moreover, they stood the various mechanical and drop tests without any difficulty.

In the same way objection was made to the addition of aluminium. Again, why?—seeing that that element, like silicon, gave the desired soundness, as Mr. Talbot himself had pointed out, and improved the physical qualities. The percentage added was so small as to be practically negligible. Mr. Talbot might be surprised to learn that good steel had been made containing not 0·05 per cent. of aluminium, but fifty times that quantity; not, of course, for rails, but as showing that material with such a high percentage of aluminium could form a commercial product. The results obtained with it proved that such small quantities of that element as outlined in the paper might be safely added without interfering with the mechanical qualities.

It was said by Mr. Talbot that he had never seen an ingot of rising or boiling nature in which 0·2 per cent. of added silicon was found in the steel after it was cast. One of the authors would be glad to show quite a number of ingots of that nature. Even with 0·4 per cent., 0·5 per cent., 0·6 per cent. of silicon it was possible to have rising steel full of blowholes, and it was surprising to learn that Mr. Talbot was not aware of the fact.

In reply to the question as to whether the sink-heads were cut off before the cold ingots were charged, that was not the case; they were rolled whilst the sand or feeding-head portion was still on the ingots. The percentage of waste, discards, losses, &c., was calculated on the ingot exactly as sent away from the steelworks, that was including its sink-head. No trouble was found in rolling down those ingots with their sand feeding-head still remaining attached. The authors could not see why it should be thought the sand-head should give trouble, seeing the material at that part was of the same malleable nature as the remaining portion of the ingot.

As regards Mr. Talbot's statement that piping did not extend low down into the ingot, he was quite mistaken. Numerous cases had been found in which the pipe went a long way down. Moreover, it was clearly proved by one of the authors in his paper to the Institute in 1912, "On a New Method of Revealing Segregation in Steel Ingots," that if there was not absolute piping in many ingots made in the ordinary way there was looseness of structure much further down than had been generally imagined, as shown by the experiments in which copper was poured into the top of an ingot referred to in the paper in question.

The advisability of casting ingots large end up was questioned by Mr. Talbot, who did not seem to be aware that many makers of steel for rails and other purposes were casting the ingots that way, and rightly so. If Mr. Talbot had studied the behaviour of ingots cast large end up compared with small end up, he would be surprised at the extraordinary difference between the two. Producing ingots cast with the large end uppermost was, of course, quite apart from the method of feeding the piping dealt with in the system described in the present paper.

If Mr. Talbot would study the accompanying Figures, Nos. 20, 21, and 22, he would see why it was so important to have the small end down and the large end up. Fig. 20 represented an 18-inch ingot with the large end upwards, showing the feeding-head in position and how it performed its duty of supplying the molten steel from its reservoir. Naturally the small end, being cold and at the bottom, would cool first, which was exactly what was wanted. The large end, where most feeding was required, was at the top and therefore remained hot longest. In other words, it was natural to expect the best feeding effect from the upper portion of the ingot with which the reservoir in the head was in connection.

Fig. 21, exactly the same size ingot but cast with the small end up, should be compared with the previous instance. It would be seen that the large end being at the bottom would remain hot the longest. Naturally the feeding and cooling action, although the ingot had exactly the same sand feeding-head, would be acting in exactly the opposite way to that shown in Fig. 20, small end down. In other words, the large end down contained most heat, and drew away the feeding material in the upper or small end in a manner which tended to produce piping in the centre of the ingot.

Fig. 22 showed the two ingots superimposed. Probably until those Figures, 20, 21, and 22, were studied carefully, it would not have been appreciated—at any rate it had not been so by many—what a very great difference might be expected in feeding effects of the upper head if applied to an ingot with the small end up, as compared with the feeding effect upon the same size ingot with the small end down. That was one of the open secrets of the reason why it was possible to produce perfectly sound ingots, any portion of which, with the exception of the discard, was absolutely sound and perfect from top to bottom. That was further amplified by showing the respective areas, as given in Figs. 24 to 28. With the small end cast up, the sectional area in the ingot, 4 feet from the base, was 296 cubic inches as against 357 cubic inches for the large end cast up. In other words, there was a difference of 61 cubic inches in favour of the large end up maintaining its heat better where it was wanted. With the small end cast down the area was smaller, as it should be, thus enabling the

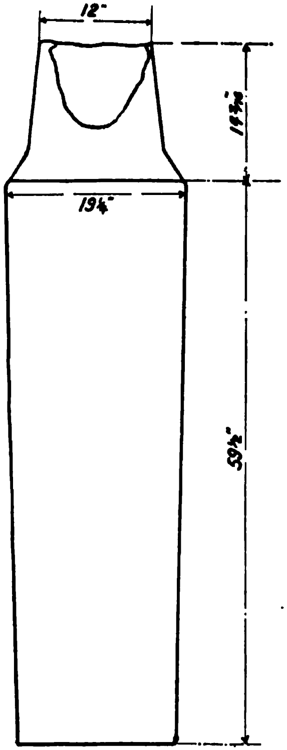


FIG. 20.

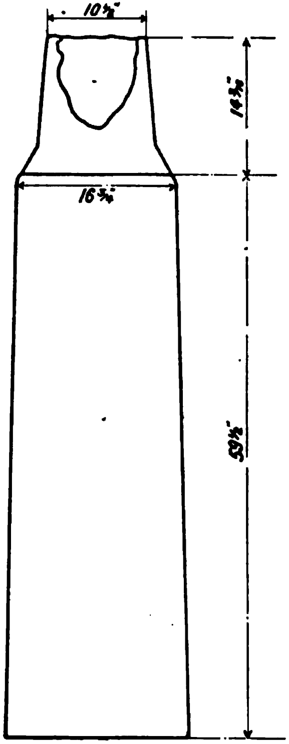


FIG. 21.

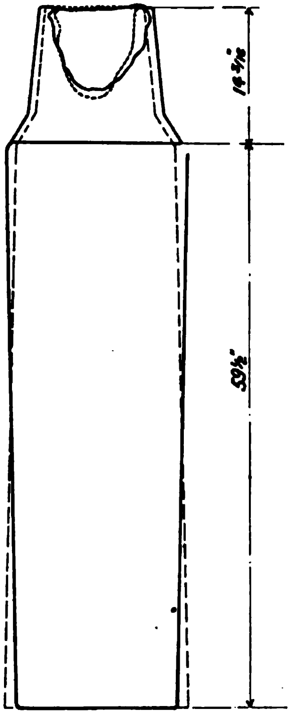
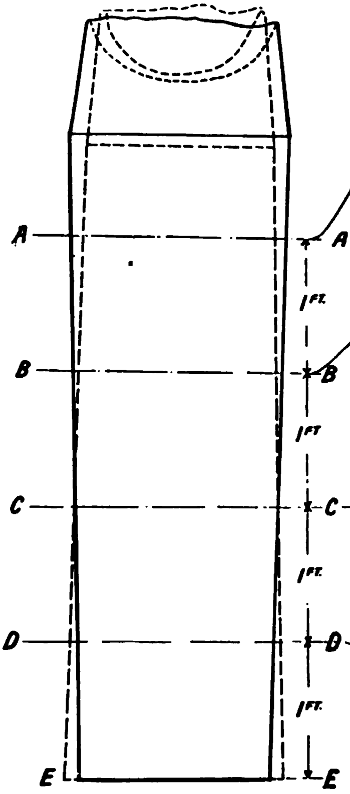


FIG. 22.

18-INCH INGOTS AND HEADS.

Fig. 23



SKETCH SHOWING RELATIVE AREAS AT FIXED HEIGHTS FROM BASE OF INGOTS.

INGOT CAST LARGE END UP ————
INGOT CAST SMALL END UP – – – – – –

Fig. 24
A

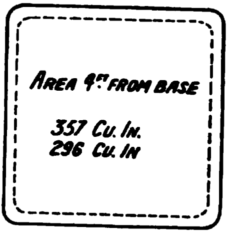


Fig. 25
B

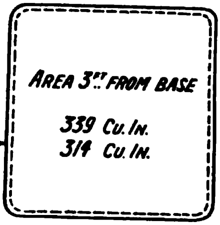
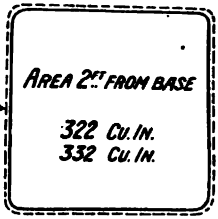


Fig. 26
C



D
Fig. 27

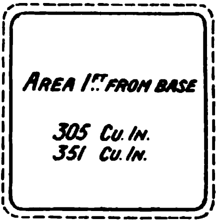
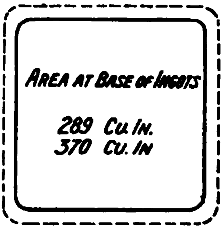


Fig. 28
E



material to cool more quickly, and later on, when the material had become cooler (not drawing away so much from the upper portion of the feeding-head), the area was 289 cubic inches as against 370 cubic inches, or a difference of 81 cubic inches in favour of the small end down.

Mr. Talbot stated that the use of the blowpipe arrangement was, in his opinion, of no value. That was a rather surprising statement. Apparently Mr. Talbot had not even tried the device on the lines communicated in the various papers by one of the authors. He seemed, like others, to imagine that the special blowpipe arrangement was the leading point. It was certainly an important one, but only in combination with the various other factors. If he would refer to the authors' reply to Mr. Robert Job's remarks he would see the five points mentioned which formed the real method or system advocated as a result of the authors' various researches. Mr. Talbot appeared quite to overlook those, and was evidently trying to criticise what he had not thoroughly understood—a very dangerous form of criticism.

The authors in no way discounted the excellent endeavours being made by a number of makers to avoid the troubles experienced from piping cavities by effecting some of the necessary feeding with brick-lined sink-heads. That, however, was only like taking one of the five points advocated in the particular system described in the paper. To obtain the desired perfection it was necessary to use all of them, as referred to above.

In the makeshift system of top cast ingots with brick-lined sink-heads, the ingots were doubtless improved, but the authors challenged Mr. Talbot to produce by that method ingots of quality equal to those made by the methods described in the research. Mr. Talbot, with all his experience, would admit that if he took 120 average ingots as made to-day in the steelworks by the ordinary processes, cut them open and compared them with the 120 ingots made by the authors' system (which was the test carried out by the British Government), those made by the ordinary methods would utterly break down under such a severe test. Mr. Talbot said that whilst good results might be obtained in small ingots, it was doubtful whether that would be so for all sizes of ingots. As the authors had already pointed out, the system described in the paper had been applied on a large scale to ingots from 2½ tons up to 25 tons in weight.

Mr. Talbot referred to certain streaks in one of the ingots, No. 8. Had he overlooked the fact that that ingot was cast narrow end up, which exactly proved the point the authors had made in their paper that it was most inadvisable to cast ingots in that manner. They ought to be cast with the large end up, and there would then be no pure iron streaks. It was rather strange to find Mr. Talbot objecting to these streaks, because they were, as the authors understood, an inherent property of steel billets, rails, and other work rolled from ingots made in the way Mr. Talbot advocated. Rolling ingots whilst the ingot was fluid gave exactly what Mr. Talbot objected to in ingot No. 8 described in the paper, namely, a centre full of streaks. In the authors' opinion those streaks were objectionable, and only occurred in ingots described in the paper as having been cast narrow end up.

Mr. Talbot stated that he had tried to make some experimental Hadfield ingots. It was quite evident from his results, as mentioned elsewhere in reply to his remarks, that he utterly failed to carry into practice the five points referred to in the authors' reply to Mr. Job, without which, or by the omission of any one of them, the great efficacy and advantage of the system described in the paper would not be obtained.

It was hardly necessary to state that Mr. Talbot's analyses in themselves did not carry conviction that he had properly carried out the method, otherwise he would not have obtained an upper surface containing nearly 2 per cent. of carbon, which was a startling performance, but not a fair one as representing ingots obtained by the use of the Hadfield system, in which the carbon, even if the upper layer or thickness were not more than an inch or so, did not in the head exceed about 0·92 per cent. It was, of course, easy enough to impregnate fluid steel with carbon, but Mr. Talbot seemed to forget that a proper application of the insulating layer of slag enabled that difficulty to be met easily and satisfactorily. Mr. Talbot's concluding remark in that connection, that there was practically no superiority in using the Hadfield method of making ingots of the size he mentioned, was hardly warranted, seeing that in his experiments he had not carried out the system in a proper manner.. If Mr. Talbot did not understand the proper working of the system he should have first communicated with the authors and asked what were the exact methods of carrying out the casting practice covered by the Hadfield system. He would have been gladly furnished with information. The authors' sole desire was to improve steel-making and show that sound steel could be easily, cheaply, and readily produced.

It was very remarkable to see Mr. Talbot's adverse criticism with regard to the rolling down of ingots of that class, that was with the sand top or feeding-head. One of the authors' firms had now had many thousands of those ingots rolled down with the heads on, and no disadvantage of any kind had been found in practice.

Mr. Talbot seemed to consider the use of the system described in the paper would involve great addition to the cost. That, however, had not been found to be the case, in fact there had been considerable economy in production resulting from the large saving in discard by the use of the system as compared with ingots made in the ordinary way. It was therefore felt certain that no trouble would be found in the various respects to which Mr. Talbot referred. Even if there was a slight extra cost (and it was well known that extras were now paid for better kinds of rails), the user would be more than repaid by the longer life of the material and, what was still more important, greater safety.

As regards the method to which Mr. Talbot referred, namely, rolling ingots with the top steel in a partially fluid or pasty condition, the question still remained, would such material be accepted for the manufacture of billets for making projectiles without the usual 40 per cent. discard being cut off? To the authors that would seem doubtful. Until Mr. Talbot could produce ingots or billets of which 85 per cent. could be used in the manufacture of projectiles it would seem useless to make comparisons; an improvement in quality surely applied just as much to the manufacture of rails as projectiles. To a metallurgist keen in his art of producing proper material, it seemed an unwarranted conclusion to say that a rail did not demand steel equally good and sound as that used for shell. The authors wished Mr. Talbot every success in his efforts to accomplish the same results in another manner, but the ideas which he had expressed appeared to be impracticable, nor should they be allowed in the case of rails, because in the first place ingots so made would run serious risk of considerable variation. In other words, even if here and there a number of them were satisfactory, there would be exceptions which of course could not be allowed for in products such as projectiles. Why, therefore, should an inferior quality of material, inferior, that was to say, to that used for projectiles, be permitted to be rolled into rails on which the safety of human life depended? That was the whole crux of the system described in the present paper, namely, to produce regular and uniform ingots, every one of which would stand the same test as if it were going to be used for projectile manufacture. On careful consideration it would be seen that the quality of steel for rails should not be allowed to be on any lower plane than that of steel for projectiles.

The idea of expecting to get a sound ingot from steel of piping nature because the metal was not allowed to become cold seemed to the authors fallacious. The steel might have apparent soundness, but one of the authors believed that so-called soundness was the source of a large number of defects. In other words, if the material were carefully examined by etching and the microstructure noticed, it would be found to be an inferior product and all the more dangerous. That method of apparently closing up defects was not an ideal one, for the metal still remained internally weak as compared with material which was quite sound in the first place.

Further, to prove to Mr. Talbot that the steel made by his liquid squeezing method would not compare favourably with the system described in the present paper, it might be mentioned that it was necessary when making steel for high explosive shell that the variations of the elements present should be within certain limits; in fact, in some cases the final carbon must not vary more than about 0·06 per cent. As that type of steel (namely, uniform in quality) could be produced without any increase in cost, why go on making inferior material? In the case of the top bloom ("liquid squeezed") shown by Mr. Talbot in one of his photographs, his own analysis on the outside showed the carbon to be 0·42 per cent., 0·53 per cent. midway, and as low as 0·30 per cent. in the interior. That was a variation of no less than 0·23 per cent., or nearly 100 per cent. difference. Those variations necessarily occurred in ingots rolled whilst the centre was liquid or pasty, that was to say the billets or blooms produced would possess varying carbon percentages, and specially a mild centre, as shown by the photograph above mentioned. The resultant steel was therefore of such varying character that it would not be suitable for many purposes, and certainly would not be accepted for high explosive shell owing to the large variations in the carbon percentages. If such steel were not good enough for shell, it surely was not good enough for rails and other purposes. In addition to the carbon variation there was even a greater variation in the sulphur percentages as shown by the figures in Mr. Talbot's own photograph. At any part of the Hadfield ingot below about 10 per cent. discard, either on the outside, half-way, or in the centre, the carbon, sulphur, and phosphorus showed practically no variation, whereas the Talbot top bloom varied from 0·39 per cent. to 0·63 per cent. carbon, and the sulphur from 0·028 per cent. to 0·100 per cent. The uniformity of the Hadfield ingot was shown by the following table:—

TABLE VII.—*Carbon, Sulphur, and Phosphorus Analyses of the Hadfield Ingot taken at Different Positions.*

Distances from Top of Ingot approximately per Cent.	Outside.			Half-way.			Centre.		
	C. per Cent.	S. per Cent.	P. per Cent.	C. per Cent.	S. per Cent.	P. per Cent.	C. per Cent.	S. per Cent.	P. per Cent.
20 per cent. from top	0·59	0·042	0·032	0·58	0·044	0·034	0·59	0·044	0·033
30 ,, ,, ,,	0·58	0·043	0·032	0·58	0·041	0·031	0·58	0·040	0·031
55 ,, ,, ,,	0·59	0·041	0·032	0·57	0·043	0·032	0·54	0·045	0·027
85 ,, ,, ,,	0·58	0·037	0·032	0·58	0·038	0·030	0·57	0·044	0·031
Variation in the elements	0·01	0·006	nil	0·01	0·006	0·004	0·05	0·005	0·006

Finally, therefore, to obtain in liquid squeezed ingots sound material of uniform quality throughout their sectional area, and free from segregation, it would be necessary to cut off a considerable portion of the billets. Moreover, even then the resultant material had objectionable features such as above pointed out, so that to produce steel of uniform character equal in quality to that from ingots made by the author's system still higher discards than those above mentioned would be necessary.

Mr. Talbot asked what was the amount of discard required to secure sound rails. The best way to answer that question was to give the accompanying Plate XI., in which would be seen (Fig. 3) the rail discard weighing 24 lbs. from the upper portion near the head of a Hadfield ingot. In other words, in the ingot from which the rail was taken the head was cut off as shown by Fig. 2, the part "AA" in Fig. 3 corresponding exactly to the position "AA" in Fig. 2; that was to say, the only discard was the amount of ingot head shown, namely, 8 per cent. of the weight of the ingot, and the comparatively small fragment of the rail itself as shown in Fig. 3.

Fig. 1 showed an etched section from the top of the rail near the head, that was the part marked "BB" in Fig. 3, showing that it was perfectly sound with 8 per cent. discard.

As a further confirmation of the extraordinary soundness obtained by those ingots, Plate XII. showed an 11-inch ingot weighing 1680 lbs. That ingot was forged with the feeding-head on, the result being the billets shown in Figs. 2 and 3. The following table represented the exact weight:—

	Lbs.	Per Cent.
Ingot as cast	1,680	100·0
Discard removed . . .	123	7·3
Sound billets	1,513	90·0

Fig. 4 showed a polished section from the top portion of the billet at the part marked "A" in Fig. 2, and Fig. 5 showed a polished section from the top portion of the billet at the part marked "B" in Fig. 2, representing about 7·3 per cent. of discard removed.

Those two Plates XI. and XII. clearly showed Mr. Talbot that even with as low as 7·3 per cent. discard, and allowing for the loss in rolling, &c., no less than 90 per cent. of sound billets were obtained. That they were sound was shown by the polished section in Fig. 4.

Further evidence might be given for special steel (not ordinary carbon steel), as shown by Plate XIII. All four ingots were rolled into billets, the amount of discard being only 9 per cent., the remainder of the billets being absolutely sound special steel (not ordinary carbon steel). The saving effected in those special steels by the method for producing sound steel was particularly important, because a large percentage of discard in expensive alloy steels meant very considerable addition to the cost.

With regard to the discard question, Mr. Talbot seemed to have overlooked the information given in his own paper to the Iron and Steel Institute in 1913, "On the Production of Sound Steel by Lateral Compression of the Ingot whilst its Centre is Liquid."

In Plate I. accompanying that paper particulars were given of two ingots—"A," containing no aluminium; "B," containing two ounces of aluminium per ton. Referring to ingot "B," containing about 0·006 per cent. of aluminium, it would be noticed that, owing no doubt to the influence of piping steel, even at a point in that ingot where no less than about 40 per cent. of discard would be taken, the carbon reached the very high figure of 0·92 per cent., and the sulphur 0·08 per cent., as against 0·65 per cent. carbon, and 0·050 per cent. sulphur in the normal part of the ingot. When the discard was reduced to, say, about 30 per cent., the carbon was no less than 1·37 per cent., and the sulphur 0·145 per cent., and just under the pipe (say about 25 per cent. discard) the carbon was 1·75 per cent., and the sulphur 0·285 per cent. That was further shown in the following table:—

TABLE VIII.—*Comparison of Carbon, Sulphur, and Phosphorus Segregation on the Centre Line of each of the three Ingots.*

Distances from Top of Ingot approximately per Cent.	Talbot Ingots.[1]						Hadfield Ingot.		
	"A."			"B."					
	(Fig. 29.)			(Fig. 30.)			(Fig. 31.)		
	C. per Cent.	S. per Cent.	P. per Cent.	C. per Cent.	S. per Cent.	P. per Cent.	C. per Cent.	S. per Cent.	P. per Cent.
5 per cent from top	...	...	...	...	...	...	0·79	0·045	0·039
10 " "	...	...	...	...	...	...	0·64	0·045	0·033
15 " "	...	...	...	...	...	...	0·60	0·030	0·029
25 " "	1·18	0·133	...	1·75	0·285	...	0·61	0·036	0·034
30 " "	1·01	0·133	...	1·37	0·145	...	0·58	0·040	0·031
40 " "	0·92	0·080	...	0·92	0·080	...	0·53	0·032	0·027
50 " "	0·66	0·059	...	0·66	0·059	...	0·54	0·045	0·027
70 " "	0·66	0·055	...	0·66	0·055	...	0·55	0·044	0·027
100 " " (Bottom of ingot)	0·62	0·064	...	0·60	0·052	...	0·57	0·039	0·031
Variations in the elements	0·56	0·078	...	1·15	0·233	...	0·26	0·013	0·012
Percentage of difference	100	150	...	200	450	...	50	50	50

As regards ingot "A," to which no aluminium was added, Fig. 29, which was taken from Mr. Talbot's paper referred to, showed that even in that case where there was no piping, the segregation of carbon in the centre for at least 40 per cent. of the total length of the ingot reached the high figure of 0·92 per cent. In the Hadfield ingots it would be noticed that when making a discard of only 10 per cent. to 12 per cent. the carbon, silicon, sulphur, phosphorus, and manganese were practically the same throughout the whole mass of the ingot, and there was of course no segregation, that was every part possessed wonderful uniformity and all the ingots were alike. The reader was left to his own judgment to draw comparisons with regard to the quality of the ingots "A" and "B" shown in Figs. 29 and 30, as compared with the Hadfield ingot in Fig. 31.

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[1] Referred to in Mr. Talbot's paper to the Iron and Steel Institute in 1913, "On the Production of Sound Steel by Lateral Pressure of the Ingot whilst its Centre is Liquid."

There could be no more remarkable proof of the dangerous nature of ingots in which piping was not properly looked after. In the

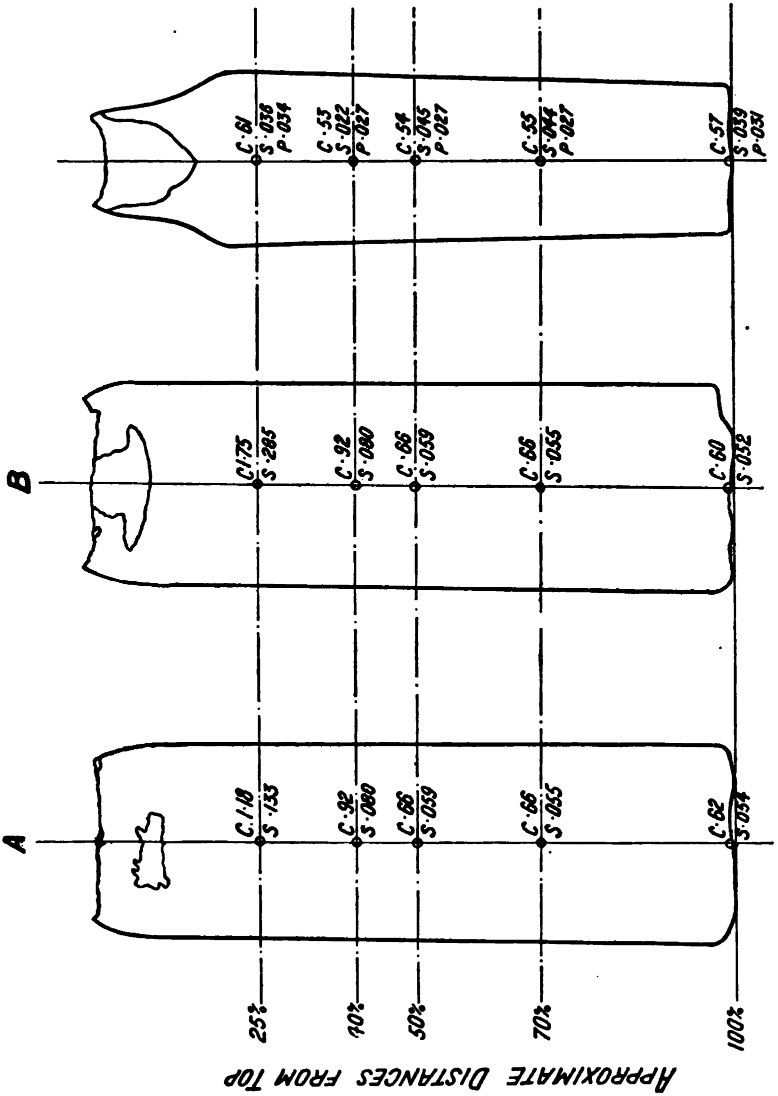


FIG. 29.—Talbot Ingot.

FIG. 30.—Talbot Ingot.

FIG. 31.—Hadfield Ingot.

Hadfield ingots that was done, consequently, as the authors had pointed out, segregation never occurred to the same extent as in ordinary ingots. Moreover, what did occur was lifted to a part which was discarded well above the 10 per cent. to 12 per cent. discard. Further, such ingots as the "A" and "B" type made by Mr. Talbot, if rolled whilst the centre was liquid or pasty, would always possess that defect of high segregation of carbon, sulphur, and phosphorus, the only benefit of lateral compression of the ingot in that condition appearing to be that it was distributed over a larger area. That was, however, no excuse for the presence of very high percentages of sulphur and phosphorus, besides dangerously increasing carbon, especially when it was considered that all the above troubles could be entirely avoided by taking the precautions pointed out in the paper.

If some of the points raised failed to convince Mr. Talbot, surely the fact that out of 70,000 tons of ingots which had been produced by the system, so far not a single rejection of material for the Government had been made by their inspectors, or others would do so.

Reply to Mr. Greville Jones.—In reply to Mr. Jones, the authors think the opening portion of the paper clearly sets forth why an ingot made in America was selected. It was really a matter of indifference where the ingots were made, as long as they were produced by present methods, in which the best attempts were not made to produce sound steel and no steps were taken to avoid piping and segregation. If such ingots were rolled into finished products—for example, rails—then those made, at any rate from the upper portion of the ingot, could not be of the high quality they should be. One of the leading permanent-way engineers in Great Britain recently stated regarding British work that "one rail out of 65 miles of track has to be taken out, either owing to fracture or other defect, each year." Whilst the present paper was in no way intended to call in question the quality of rails made at home, if, however, improved quality could be obtained it was advisable to adopt all the latest and best improvements in method which reduced the large amount of risk, often unknown to the public, in railway travelling. Great credit was due to the engineers supervising the tracks of important British railway systems for the care and watchfulness they showed, as otherwise there would doubtless be many more serious railway accidents.

Reply to Mr. Stromeyer.—In reply to Mr. Stromeyer, the authors thought that gentleman hardly seemed to realise that much steel was rolled with piping or incipient piping, consequently the resulting product was more or less weak, as could be at any time readily determined by making transverse tests from such material. He would find that such steel was surprisingly weak, and was probably often the cause of so-called mysterious failures. Surely Mr. Stromeyer did not mean to suggest that, with sound steel, failures would be as numerous as with products made from unsound steel. If so, he was running contrary to all metallurgical axioms. He stated, "Fractured steels are not due to piping but to defective material." It was, however, piping which helped to make material defective. The failures referred to in America in cold weather were generally traceable to defects such as those mentioned, which by the methods indicated in the paper were avoided.

Reply to Mr. Hewlett.—The remarks made by Mr. Hewlett were very pertinent, and although brief, represented the summing up of the whole of the objects of the series of papers undertaken by one of the authors during the last two or three years, namely, to produce sound steel in which not only was the piping reduced and loss of material avoided, but the segregation and inferiority obtained with unsound material reduced.

Reply to Mr. Harbord.—In reply to Mr. Harbord's question as to whether the authors had the figures for the seconds in the first and third quality rails from No. 10 ingot, namely, the American ingot, that ingot could not be rolled, as it was cut up, therefore there was unfortunately no comparison. Sir Robert wished to call Mr. Harbord's attention to the accompanying Plates XI., XIII., and XIV. Plate XIV. showed ingots made by the sound steel system described in the paper, rolled into rails, from which it would be seen that a total of no less than 89 per cent. of first quality rails was obtained. Plate XI. represented an ingot from which the rail discard had been carefully cut off and etched. The total discard amounted to only 8 per cent. of the ingot. In Plate XIII. was also given a very complete statement with reference to similar ingots cast by the sound steel system, rolled into billets.

Reply to Mr. Twynam.—The points raised by Mr. Twynam had already been dealt with in previous papers on the same subject. When using the system described in the present paper there was no appreciable impregnation of carbon; in any case, the small amount existing was confined to a very small portion of the steel immediately under the head. In practice the carbon percentage never exceeded about 0·90 per cent. That was to be expected, as, by means of the insulating slag, carbonising could not take place through that layer. The accompanying Plate XV. showed the average results obtained with the sound steel ingots referred to, from which it would be noticed that the carbon ran down to the normal within a very short distance from the top.

Reply to Professor McWilliam.—Sir Robert was glad to note Professor McWilliam's remarks. While he (Sir Robert) had never advocated the abolition of inspectors, he had suggested putting them in the right place, that is, at the commencement or origin of the steel, immediately after it had been cast. The authors were quite prepared to show that a system of inspection of that kind could be easily and successfully applied in such a way that the manufacturer would in the end be far better off and would much prefer such a system. Professor McWilliam rightly pointed out the serious cases met with in ingots having (*a*) rising tops and (*b*) piping tops, therefore there could not be a better argument for doing away with the defects arising from such ingots in those two classes by a system such as described in the authors' paper. There was not the slightest question, as Professor McWilliam pointed out, but that if sound steel were produced with the piping properly taken care of (as in the ingots referred to in the present paper), and not merely feeding, but feeding on scientific lines such as set forth in the paper were adopted, not only would the inspector sleep more easily at night, but the manufacturer would also sleep more soundly.

Reply to Mr. Cooper.—In reply to Mr. Cooper, the authors wished to point out that many ingots were now used in which there was incipient unsoundness or segregation. Such material might satisfactorily stand the wear and tear for several years, but a time came when under special stress the internal weakness which existed developed; hence the great desirability for obtaining sound steel free from segregation and piping. The British Government specifications, to ensure that ingots were not used in which the above-mentioned bad qualities existed, demand 40 per cent. discard. In other words, if Mr. Cooper were to furnish ordinary ingots the Government would insist upon 40 per cent. discard, which was almost the 50 per cent. referred to by him in his remarks. It had to be remembered that the object of that and previous papers was to avoid the possibility of any one ingot amongst tens of thousands being unsound or defective, and that was what the system advocated accomplished. It was, of course, quite easy to make a number of ingots which passed the tests satisfactorily; but occasionally, in fact at present far too frequently, those of irregular quality were produced. As it was often not possible to detect those ingots of irregular quality, good and bad alike were forged into products for actual service. Eventually a breakdown of material occurred, often with serious results, whether as regards rails, tires, axles, and other applications.

Reply to Dr. Hatfield.—In reply to Dr. Hatfield, ingots cast from the bottom had been made by the system. So far as the tests had gone, they appeared to be satisfactory and similar in quality to those produced in the ordinary manner. Nevertheless, the method of casting ingots singly, small end down, large end up, poured from the top, and treated by the system mentioned in the paper, was without doubt the most certain way of ensuring perfect ingots. In fact, that was now readily accomplished not only for small or medium, but for the very largest quantity, and tens of thousands of tons had been produced and passed into service made by that system, figures which would before long run into hundreds of thousands of tons.

Reply to Mr. Rowlands.—The authors recognised that whilst Mr. Rowlands' remarks were of considerable interest, he spoke of a method of making sound steel by means of a fireclay head with charcoal, and later feeding with the same class of steel. Such a method would have been of no use for application to the 70,000 tons of ingots of which the authors speak. The addition of carbon in the manner mentioned would probably mean carbonising to some 20 per cent. or more of the upper portion of the ingot, consequently the product would be inferior and brittle. Moreover, it would not be uniform. Mr. Twynam asked a question about this point. Evidently he imagined the ingots described in the paper were subject to that defect. They were not so, as was clearly shown by Fig. 4 in the paper.

As regards the effect of the addition of aluminium and its producing alumina, the proof of the pudding was in the eating. Dr. Burgess showed by his tests that the average quality of the rails produced from the Hadfield ingots was much superior, and was effected in such a way that it was impossible for alumina to be present.

Reply to Mr. Sandberg.—With reference to Mr. Sandberg's interesting contribution, the authors greatly valued his comments in view of his long and varied experience with regard to steel rails. In reply to his suggestion as to cutting up more ingots, they might say that no less than 120 ingots were cut up under the most severe possible conditions and examined by the inspectors for the War Office and Admiralty. Moreover, as 70,000 tons of ingots had now been produced by the method it would be seen that it had long passed the experimental stage. The results obtained in practice fully bore out those claimed when the system was first introduced.

Reply to Mr. Scott.—It was satisfactory to note that Mr. R. G. Scott, who had had long experience in producing steel of high quality for railway and other purposes, considered that research should prove of value to the steel-maker. The authors noted with much interest his remarks regarding the Harmet system, and that the facts noticed in the cooling down of ingots made by that method corroborated the claims they (the authors) had put forward. As regards the suggestion in the concluding portion of Mr. Scott's remarks, the authors did not quite understand what he meant. The tests referred to in that paper were carried out in a definite way for a specific purpose. The further tests mentioned by Mr. Scott would not have thrown any more light on the points which it was the object of the authors' paper to elucidate. Moreover, the authors would again draw Mr. Scott's attention to the fact that before that system was allowed to be used on a large scale for steel required by the British Government, no less than 120 ingots were cut up, not one of which was found to be imperfect. That surely answered Mr. Scott's questions, and gave what he termed a "true comparison of ordinary and improved practice," for if ingots made in the ordinary way would not stand that test—and they would not, for proof positive existed to that effect—why should steel-makers adhere to their old methods of wasting 30 per cent. to 40 per cent. of their product? Moreover, as Mr. Scott was well aware, those who handled steel of high quality knew that if a much less number than 120 of such ingots were cut open a very large portion of them would have to be rejected, as they would not meet the specification.

Why should ingots for rails be allowed to be any less perfect than steel required for high explosive shell, seeing that the safety of human life depended upon their quality?

Reply to Mr. Service.—In reply to Mr. Service, the mould used with the narrow end down was simply one with the wide end up, inverted. No difficulty had been found on the point mentioned by Mr. Service in the manufacture of large numbers of ingots, now tens of thousands. The authors certainly thought that if material of similar nature to that used for the American ingot had been poured into properly fed moulds there would have been great improvement in its quality. Mr. Service referred to ingot No. 6. That, of course, would have given the same result as ingot No. 1 had it been prepared by the Hadfield system. Ingot No. 7 could not be expected to be sound, because it was made of unsound steel such as was often used. That was one of the main portions of the experiment. Mr. Service's description of the Hadfield method was rather amusing. He said that the metal in the head had to be covered with slag and coke, and air under pressure supplied to ignite the coke, and keep the metal in the head fluid. That, of course, was not correct; coke had not been recommended. Besides, the metal in the head was not covered with charcoal or coke. The addition of coke to the top of the fluid steel was most expressly to be avoided. If Mr. Service would carefully read the description in the various papers, he would see the exact methods set forth. The authors did not recommend that comprehensive method of covering the ingot with slag and coke. They could therefore hardly be expected to answer questions not within the scope of their various papers on the subject. After having devoted so much time to making clear the methods employed, it was somewhat disappointing to find statements discussed which the authors had never made. That method of criticism was common, although no doubt often unintentional, but it was hardly complimentary to authors of papers.

The authors did not understand Mr. Service's point in his remarks concerning ingots Nos. 8 and 9, as those were of ordinary rail steel like ingots Nos. 1, 2, and 4.

The addition of aluminium did not produce pasty metal. The other points raised by Mr. Service were fully answered in the papers themselves and in the replies to others who had contributed to the discussion.

Reply to Dr. Stead.—In reply to Dr. Stead's remarks, the authors were glad to note that the evidence set forth in the paper satisfied him that sound ingots could be readily produced. As Dr. Stead pointed out, there was no reason why the same method should not be applied to the production of special steel ingots of the largest sizes. As a matter of fact, Mr. Charpy of Les Usines Saint Jacques, Montluçon, had made an ingot of that type weighing over 25 tons. He informed one of the authors that he was in every way satisfied with the results, which were a considerable advance on ordinary practice.

The authors were, however, rather surprised to note that Dr. Stead thought that honeycombed ingots would make safe rails. Rails might be produced which stood the work, but surely they could not practically be considered "safe." Rolled steel from ingots which were originally unsound would, as the authors had proved over and over again, not stand the same shock and other tests as when made from material which was sound and properly fed. Moreover, as before mentioned, one of the leading railroad engineers in Great Britain had made the important statement that one rail per 65 miles of track had to be taken out each year, either owing to fracture or other defect. That tended to confirm the fact that if honeycombed ingots were being used, that was a partial explanation of the failures mentioned. There was also no necessity for making honeycombed ingots, with the attendant risks run by the use of such material, as such a condition of the steel could be readily avoided.

Reply to Messrs. White-Boycott and Colley.—The contribution from Messrs. R. White-Boycott and A. Colley was very valuable, because their remarks were made after seeing the system at work. If it were true that an ounce of practical proof was worth a ton of theory, their contribution could be valued accordingly.

Reply to Mr. Belnap.—The authors were very pleased to note the many contributions to the discussion from metallurgists and railroad engineers in America. They agreed with Mr. Belnap that it was most desirable that the highest quality of material should be used for rails, and that in many ingots made on the other side of the water it was necessary to have very considerable discard before a safe, sound product was obtained. The authors claimed that just as high quality steel was required for rail manufacture as was used for high explosive shell. That quality could be produced without any extra expense, in fact, at less cost than now, owing to the saving in steel by the reduction in discard and waste of product. As Mr. Belnap was aware, a number of rails made from the Hadfield ingots were already in service, and a further large number would shortly be put into service. The authors ventured to predict that exceedingly good results would be obtained from material such as described in the paper, which was known from its origin to be sound, free from piping, segregation, and other defects.

Reply to Mr. Cushing.—In reply to Mr. Cushing, the apathy to which he referred, namely, the preference of makers to go on making a large discard, was hardly the point under consideration. If a large discard meant 15 per cent. or 20 per cent. with ingots made in the ordinary manner, such a discard was not sufficient to ensure soundness. The British Government demanded no less than 40 per cent., because they knew that safe shell could not be obtained from ordinary steel with less discard. To give a discard of 25 per cent. to 40 per cent. was poor business, besides even with such discards absolutely sound steel was not obtained. As the making of a safe rail was as important as to make a safe projectile, a system should be introduced such as that described in the paper. It surely could not be argued that it was preferable to make unsound steel because it was cheaper. That would be a very poor argument, especially when, as shown in the paper, sound steel with its lower discard could really be made more cheaply than unsound steel.

Whether other steel-makers accepted the statement or not, the fact remained that his (Sir Robert's) firm could produce far more cheaply by the sound steel system described in the paper than if they made ingots in the ordinary way. Moreover, 70,000 tons had been made, of course successfully, by the system, and it was scarcely possible to present stronger proof of its advantages than that.

Incidentally it might be mentioned that there was no doubt in the minds of the authors that the transverse fissures referred to in Mr. Cushing's remarks, shown in Plate XX., arose from internal unsoundness which originally existed in the ingot. Minute micro-examination showed that those flaws had their centre in segregation or unsoundness spots. That was but another argument proving the importance of using steel which was, in the first place, absolutely sound—in other words, as sound as that which had to be employed for the production of steel used in the manufacture of high explosive shell. It had been proved over and over again, unfortunately with loss of life to those at the front, that certain shell, not those made for the British Service, had given way during the firing and burst prematurely, with consequent serious loss of life and morale. In the authors' opinion, however, that was no worse nor was it very dissimilar from the serious accidents which resulted from flaws in rails or other steel products which could be readily avoided by the use, in the first place, of sound steel made in the manner described in the paper.

Reply to Dr. Dudley.—Owing to Dr. Dudley's long experience, his contribution was specially welcome. The authors, however, did not agree with some of his conclusions. For example, Dr. Dudley pointed out that the seconds in the rails referred to in Table II. of the paper were considerable. That was not really the case; there were no seconds in the ordinary sense of the term. In reply thereto the authors would ask Dr. Dudley to read their reply to Mr. Harbord's remarks, and to study the accompanying Plates XI., XII., and XIII. Without casting any reflection as to the amount of seconds that were obtained by some of the rail mills to which Dr. Dudley referred, it was quite evident that the soundness of their products was not what it should be, otherwise there would not be the considerable number of breakages which were found to occur in practice. If Dr. Dudley would also read one of the authors' papers recently read before the Franklin Institute entitled "Sound Steel for Rails and Structural Purposes" (two communications), he would see that the system had been used in a very large way and thoroughly proved satisfactory both by the manufacturer and the user, whether as regards soundness or mechanical tests.

Dr. Dudley referred to a favourite theme, that if piped ingots were rolled hot the piping effect was lost. Whilst a certain amount of difference might exist, it was most positively proved that the hot rolling of ingots having either pasty or semi-fluid steel cavities would not avoid the defects produced by unsoundness or shrinkage of steel, which was natural to all steel on cooling down from the liquid to the cold state. By the use of sound steel ingots such as referred to in the present paper, the troubles now experienced would be entirely avoided.

The question of the amount of shrinkage or cavity was dealt with by one of the authors in a further paper to the Franklin Institute, entitled "Sound Steel for Rails and Structural Purposes." Dr. Dudley's interesting experiments in that direction in the past had led one of the authors to follow up the matter in a very exhaustive manner, as would be seen from the paper above mentioned.

As regards ingots made under Dr. Dudley's specification, the ingot shown in Plate I., Fig. 2, of the accompanying paper, and again illustrated in Plate XVI., Fig. 2, for comparison, must have been produced by that particular method, as it was similar to that shown by Dr. Dudley as representing his practice in the paper read by him before the American Institute of Mining Engineers on "Piping and Segregation of Ingots of Steel and Ductility Tests for Open-hearth Steel Rails." Those ingots were shown side by side in Plate XVI., Figs. 2 and 3, in order to compare them with each other and with the Hadfield ingot, Plate XVI., Fig. 1.

The various remarks of Dr. Dudley with regard to the effect of cold were most valuable, and formed a welcome addition to the discussion. Dr. Dudley stated, however (with what authority it was difficult to understand), that even if the rails were rolled from Hadfield ingots the fractures would not be materially reduced when tested in severe climates. That was rather a strong statement, seeing Dr. Dudley had no direct evidence. The authors could positively prove that if steel were used which in the first place was absolutely sound and free from pipes and segregation (which was not the case with steel ordinarily made), it would show so much greater strength that without doubt the number of fractured rails would be considerably reduced, even under the cold weather conditions referred to by Dr. Dudley. In confirmation of that statement the authors would again quote the application of ingots, made by the sound steel system described, to projectile manufacture. If such ingots as referred to by Dr. Dudley made under his specification for rails were submitted for projectile manufacture, judging by the sketches accompanying Dr. Dudley's own papers, most of them would be rejected. As there was no question about that point, the authors felt they should again strongly emphasise the following fact, namely, that steel was now being made and used for rails which would not be accepted in steel for high explosive projectiles. Why was that? Simply because rail steel as at present produced was not sufficiently sound. Ingots made by the Hadfield sound system, whether as regards acid or basic steel, had no less than 85 per cent. of their product accepted and allowed to be turned into high explosive shell—in fact, even 90 per cent. of the steel could be turned into safe high explosive shell—whereas an ingot made by Dr. Dudley's system would not be accepted at all, or would have at least 40 per cent. rejected. That was surely the best answer to much of the criticism, not only on that point, but as regards the quality of the ingots now made by Dr. Dudley and others. In other words, and the authors wished to emphasise the statement strongly, what was not considered good enough for projectiles was certainly not good enough for rails. As that axiom was evidently not accepted by Dr. Dudley and others, the authors begged to point out most emphatically that there was no wonder many rails now broke in service, and would unfortunately continue to do so, notwithstanding the remedy offered for the production of sound steel.

There was one further question the authors wished to put to Dr. Dudley. How was it that failures generally occurred in the "A" rails—that was rails produced from the upper portion of the ingot? If the material were perfect in that part of the ingot, why did failures occur? There was no doubt that by the sound steel system described in the present paper there would be no failures, as unsoundness and segregation were done away with, for the upper portion below the discard was just as sound as the bottom portion. The reason why there were more failures from rails produced from the "A" portion of ingots made in the ordinary way was simply because the ingots were more unsound at that part. If ingots which were allowed to go cold showed certain defects, such defects would still exist in the ingots whilst hot, and they would be but rolled out and lengthened, not avoided. They might not be apparent, but they were there, and weakness existed. In view of the extraordinary number of rail failures in America, Dr. Dudley's statements did not agree with the facts to which the authors now referred. As regards that point, the authors wished to call attention to the fact that it had been officially stated that in America during the last twelve years broken rails had caused no less than 230 accidents per annum.

Dr. Dudley's remarks regarding the subject of interior transverse fissures were most valuable, and there was no doubt much truth in the argument he put forward as to the cause of those fissures. That had, however, nothing to do with the question of sound steel. Moreover, it was quite evident that the sounder the steel the less likelihood there was of fissures. The first step towards the curing of faulty rails was to make ingots which were not faulty.

It should not be forgotten that the ingots referred to in the research were allowed to go cold. A visit to the semi-scrap heap of a large American rail mill would show that there were often a thousand or more tons of ingots which had accumulated during various breakdowns of the mill, and had therefore been allowed to go cold. The result was a very poor lot of ingots; many of them were covered with cracks and consequently such ingots would yield a very large proportion of seconds. Probably those cracks would not have been present if the ingots had not been allowed to go cold. If, therefore, the particular ingots referred to in the authors' research had not been allowed to go cold there was no doubt there would have been no trouble met with in the respect to which Dr. Dudley referred, so the argument which he quoted acted both ways. As a matter of fact, the rails rolled from those ingots were particularly good, and therefore less subject to cold cracks than the ordinary type of ingot. Moreover, as Dr. Burgess pointed out, the manager of the rolling mill misunderstood certain instructions with regard to the rolling of those ingots, the result being that more scrap than was necessary was cut from the billets and rails produced.

The authors thought that if Dr. Dudley would roll rails from American ingots that had been allowed to go cold and compare them with the ingots fed by the Hadfield system, it would throw quite a different complexion on the matter. Moreover, any defects in the ingots allowed to go cold must more or less exist if the ingots were rolled hot. Merely rolling ingots which were not sound in the first case, or which had too much piping, had no effect in stopping the segregation. By the Hadfield system, that segregation was entirely avoided.

It was noticed that Dr. Dudley spoke of the ingots referred to in the paper as being made from the basic open-hearth. That was not so; they were made by the acid converter method, and from ordinary Bessemer pig iron. The criticism with regard to that point therefore fell to the ground.

The remarks regarding damage produced on rails by gagging were most important. No doubt Dr. Dudley's expert knowledge would eventually find some way of avoiding the serious stresses so brought to bear on rails. Nevertheless, rails made from sound steel would stand more gagging than rails made from comparatively unsound steel.

In conclusion, why did not Dr. Dudley adopt the wise plan now being followed by the Pennsylvania Railroad, and order from the authors, say, 100 tons of ingots made by the method now described, and have them rolled into rails. The results in practice would quickly decide the various points which Dr. Dudley had mentioned. There was not a shadow of doubt in the minds of the authors that the results would prove far superior to those obtained from rails made by the existing imperfect methods, and the sooner railroad directors and engineers realised that the more quickly would their bill resulting from accidents and very frequent misplacements be reduced.

Reply to Mr. Hibbard.—The authors are glad to note the remarks of Mr. Hibbard, who had rightly pointed out that the American ingot selected might have been seriously worse, in view of the usual run of rail ingots containing a series of skin holes in the upper end, thus adding to the difficulty of obtaining sound material in the forged or rolled product.

As regards the remarks that segregation was not known in crucible steel, whilst it was less than in ordinary steel, it was not because the material was crucible steel, but owing to the fact that the raw materials used in the manufacture of crucible steel were usually much lower in sulphur and phosphorus than the ordinary stock used for acid, converter, and open-hearth practice. In other words, if an inferior crucible steel were taken, somewhat high in sulphur and phosphorus, there would be segregation similar to that existing in ordinary steels. Moreover, even if the sulphur and phosphorus were low, there would still be segregation of carbon in the best crucible steel.

In unsound steel there were irregular patches, and in piping steel not properly fed the segregation congregated round the pipe. It was exactly for that reason that the sound steel system described in the present paper avoided those bad qualities, because there was no pipe round which to congregate.

With regard to the question of solidifying, the ingots could be safely handled in about forty minutes after the end of the casting operation, but that time could no doubt be considerably reduced. It should not be forgotten that in, for instance, a 15- or 20-ton heat, it required quite twenty minutes to cast the row of ingots; a considerable portion of the time of waiting was therefore not lost. There was no question that the points to which Mr. Hibbard rightly referred could be readily surmounted in practice.

Reply to Professor Howe.—Professor Howe pointed out certain differences in segregation percentages, but he should not forget that the upper layer of the steel was slightly carburised. That carburisation was, however, under thorough control, as it had never been found to exceed about 0·9 per cent., owing, as the authors had shown elsewhere, to the wonderful effect of the insulating slag, a point which so many seemed to overlook. Moreover, that carburisation only occurred as quite a thin layer at the top, and was, of course, cut off with the sand-head. Tens of thousands of ingots had been made in that way, and there had not been found one ingot with defects of the kind mentioned by Professor Howe.

As regards the hardness numbers quoted, the authors could not understand why those were referred to, as they had nothing to do with

PLATE XI

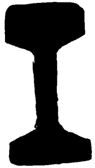


FIG. 1.—Etched Section from Top of Rail near Head.

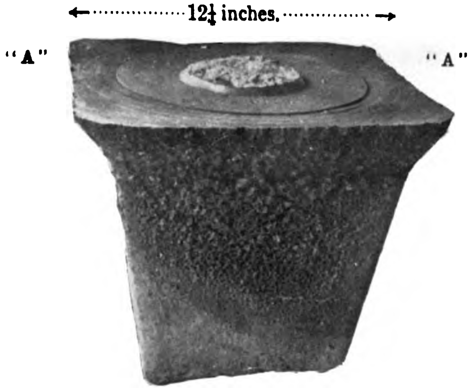


FIG. 2.—Ingot Head showing Sound Fracture representing only 8 per cent. of Ingot.

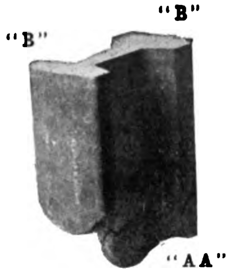
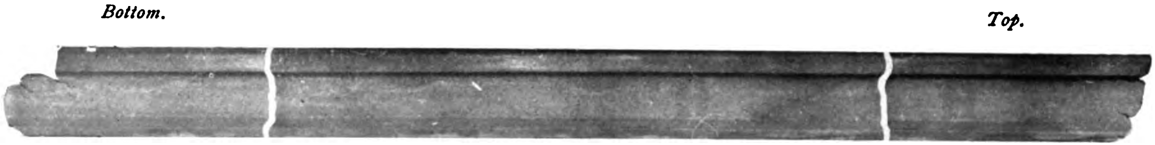


FIG. 3.—Rail Discard weighing 24 lbs. near Head. This portion "AA" came from immediately under the Ingot Head shown in Fig. 2.



←…………………… FIG. 4.—Total length of Rail wholly free from defects, 62 feet 7 inches. ……………………→

←…………………… „ „ „ „ 64 „ 0 „ ……………………→

TOU

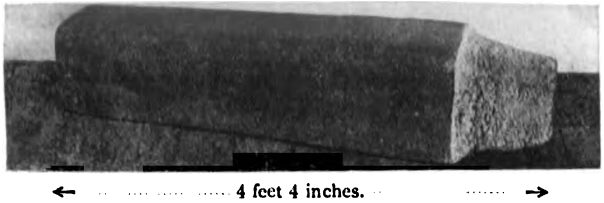


FIG. 1.—11-inch Ingot (weighing 1680 Lbs.).

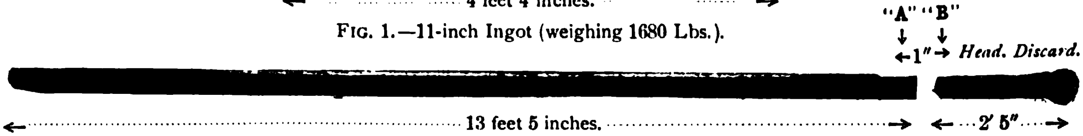


FIG. 2.—Billet from Top Portion of Ingot.

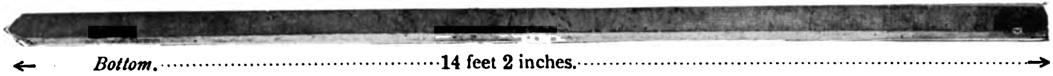


FIG. 3.—Billet from Bottom Portion of Ingot.

Ingot as cast, 1680 lbs. = 100 per cent. Discard removed, 123 lbs. = 7·3 per cent. Sound billets, 1513 lbs. = 90 per cent.

Polished Section from Top Portion of Billet
at part marked "A" in Fig. 2.

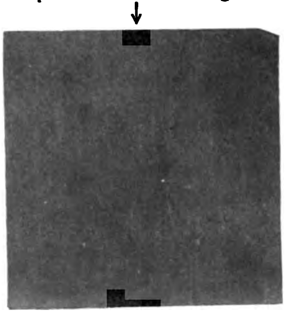


FIG. 4.

SOUND
At part marked "A,"
Fig. 2.

Polished Section from Top Portion of Billet
at part marked "B" in Fig. 2.

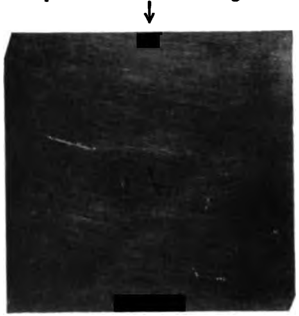


FIG. 5.

Showing last traces
of Piping near Head
at part marked "B,"
Fig. 2.

PLATE XIII

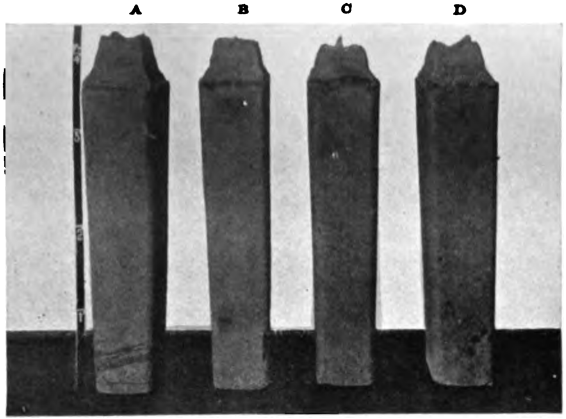


FIG. 1.—Ingots cast by Patent Method.

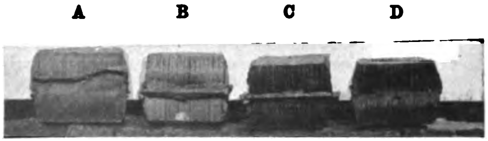


FIG. 2.—Heads from above Ingots partly cogged and then cut off.

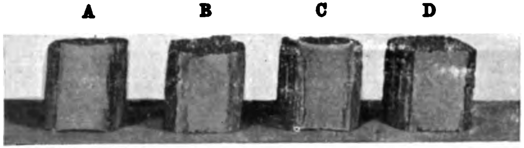
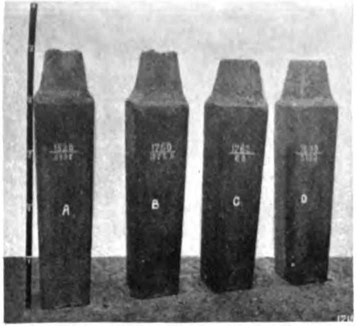


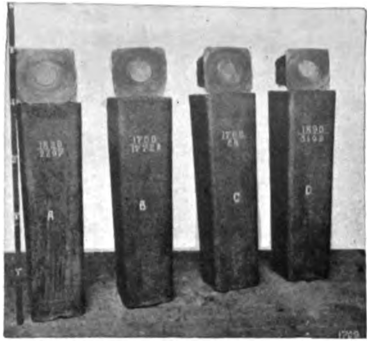
FIG. 3.—Fractures from the Upper Ends of Top Billet from each of the above Ingots.

FIG. 4.—Sound 4-Inch Billets representing 90 per cent. of the total weight of the above Ingots.

PLATE XIV



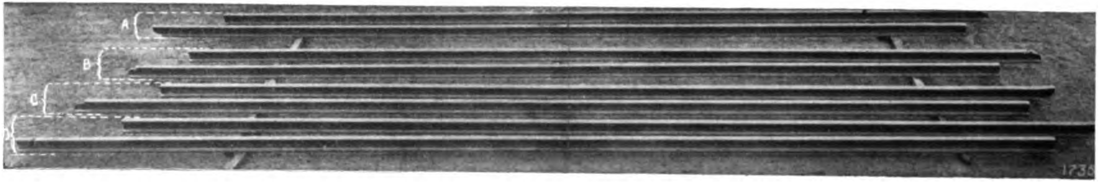
Ingots produced by the Hadfield Method as applied to Rail Manufacture.



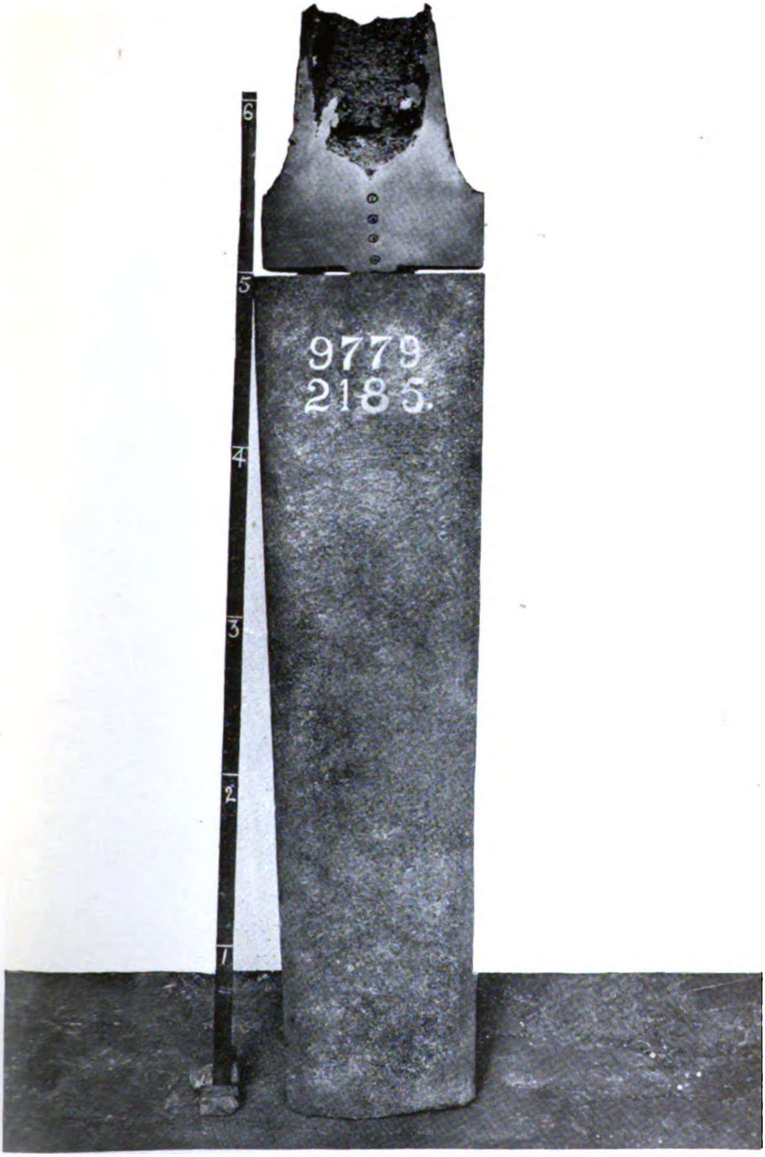
Sound Ingots showing Discard.

	Lbs.	Per Cent.
Total weight of four 12-inch ingots .	9100 =	100·0
Weight of sound ingots . . .	8376 =	92·5
Weight of rails free from pipe . .	8064 =	89·0

The above loss includes waste and oxidation from heating and during rolling.



Uncropped Rails from the above Ingots. Rolled in one length of 63 feet and afterwards cut to length.



	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.
1 . .	0·72	...	...
2 . .	0·66	0·101	0·064
3 . .	0·65	...	...
4 . .	0·62	0·097	0·061

PLATE XVI

HADFIELD INGOT.
Referred to in this paper.

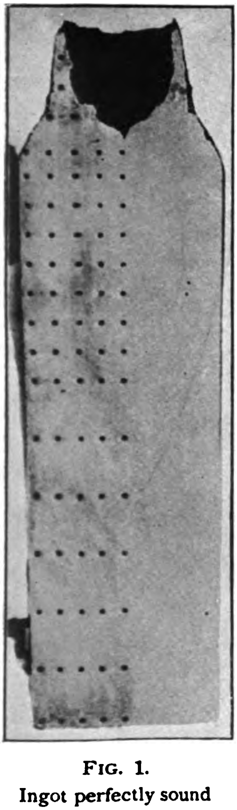


FIG. 1.
Ingot perfectly sound throughout.

AMERICAN INGOT.
Referred to in this paper.

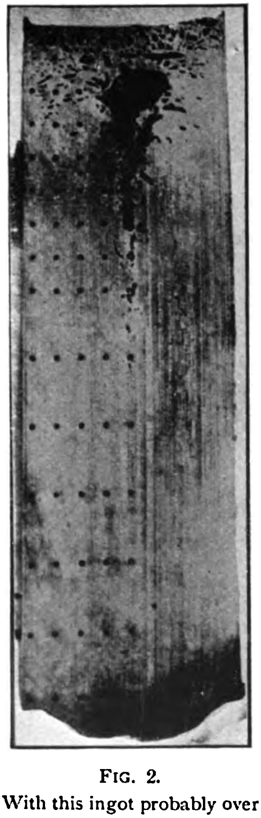
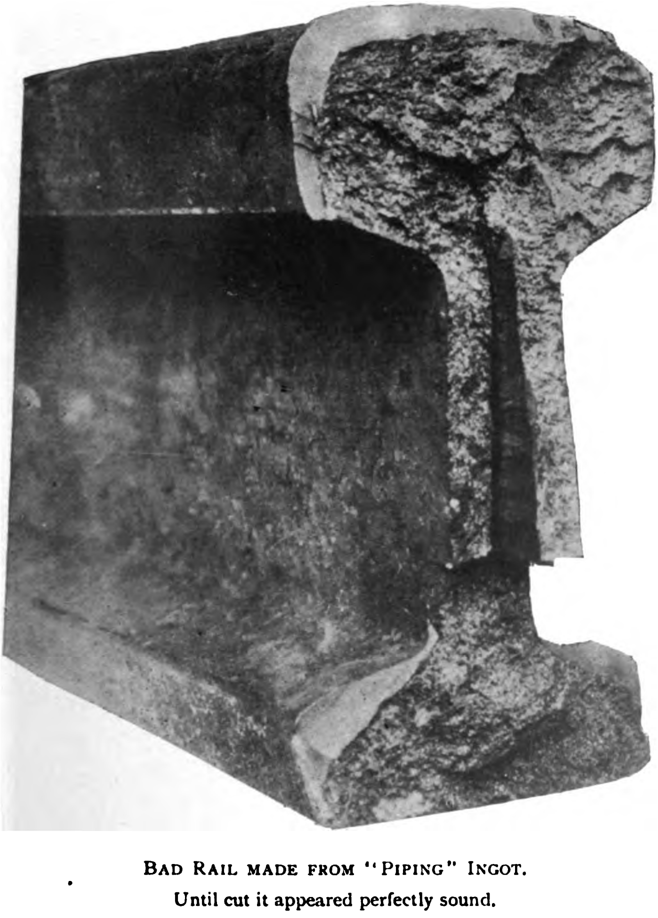


FIG. 2.
With this ingot probably over 30 per cent. discard would be required.

AMERICAN INGOT.
Referred to by Dr. Dudley and taken from his paper.

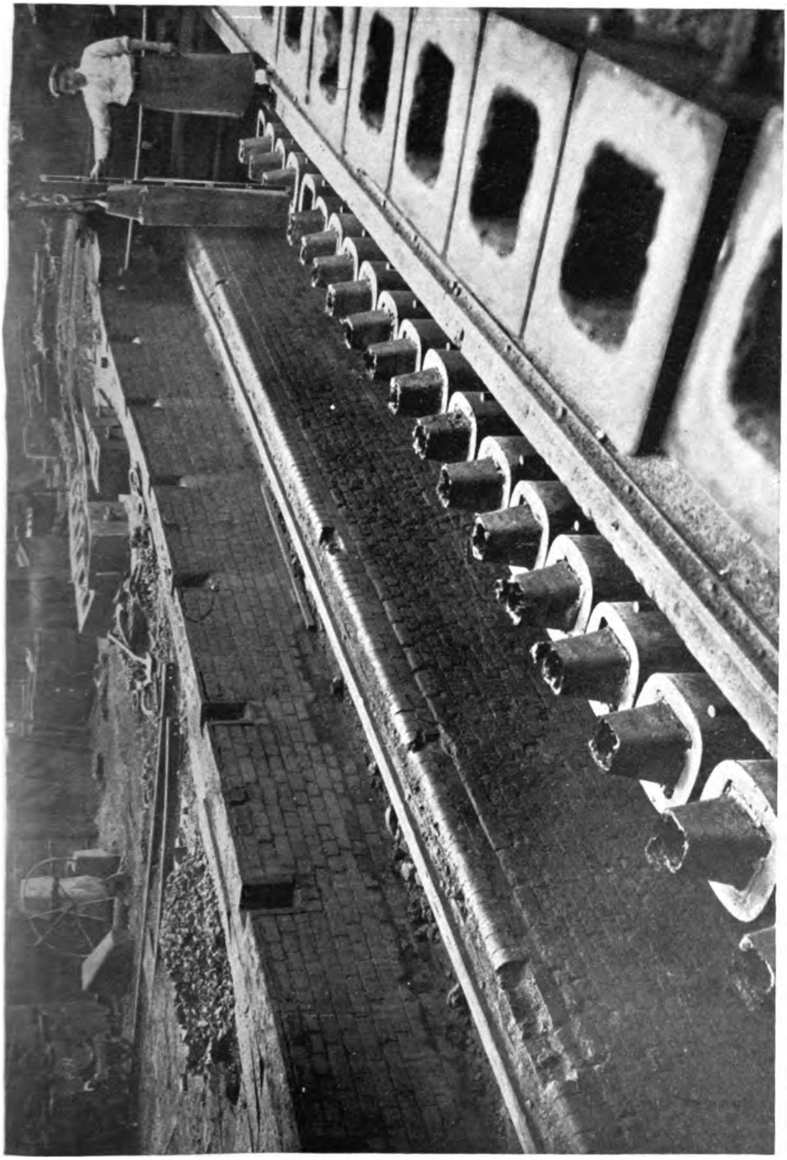
FIG. 3.



BAD RAIL MADE FROM "PIPING" INGOT.
Until cut it appeared perfectly sound.

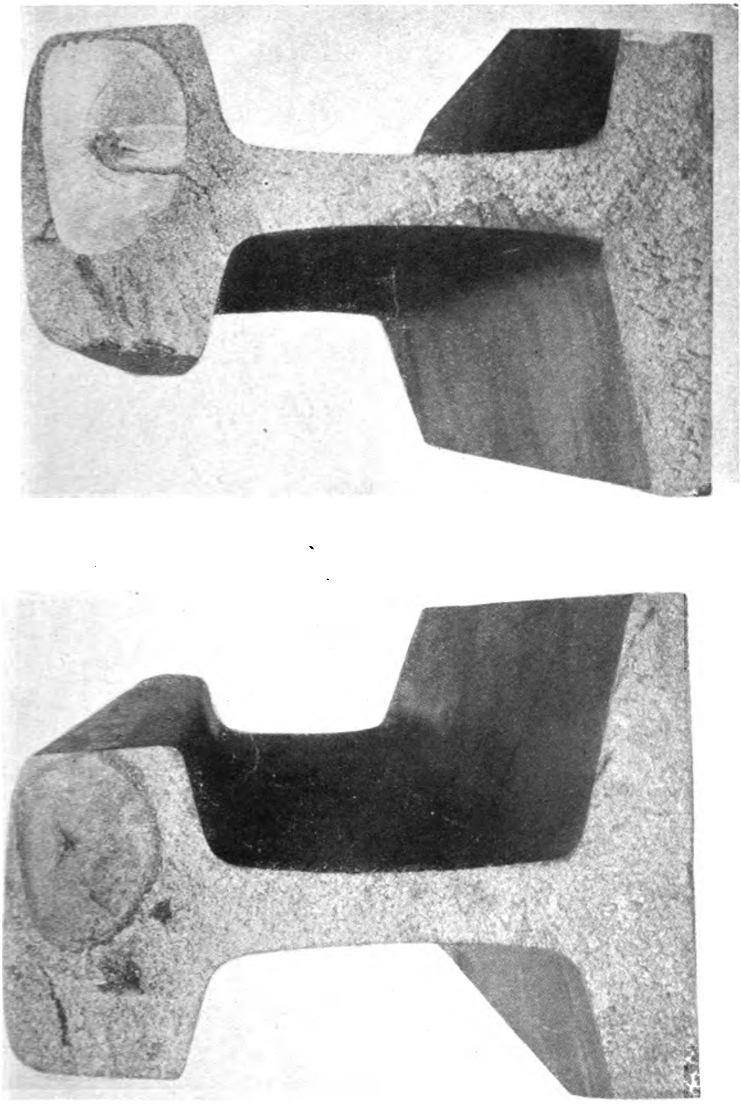
U of M

PLATE



View of Casting Pit after Casting.

U of M



TYPICAL TRANSVERSE FISSURES.

the efficiency of the rail produced. The average uniformity of the rails produced from the sound ingots made by the system described was far superior to any other method. Further, those were not the statements of Sir Robert himself but of Dr. Burgess and others, who had, of course, had nothing to do with the manufacture of the steel or with the carrying out of the process.

If Professor Howe thought that 20 per cent. discard on the American ingot would have removed the inferior material, let him submit such products, whether in ingots, billets, bars, or forgings to his own Government or the British Government, to be used for projectile manufacture. It was quite certain the result would be complete rejection of such ingots, or at any rate at least 40 per cent. would have to be cut off. Mr. Hibbard, who had contributed to the discussion, also pointed out that the American rail ingot was above the average because it did not contain a series of skin holes in the upper end. A system which was good for producing sound steel for high explosive shell was quite as good and satisfactory for rails, which surely were as important, seeing that human life depended upon their quality.

Professor Howe's concluding remarks appeared to mean that the defects which were cured by the Hadfield system were so unimportant that they did not cause breakages. If, however, reference were made to a few of the reports of the Interstate Commerce Commission, it would be there seen that nearly every breakage reported by that excellent commission had arisen from defects which could be, and were, readily cured by the sound ingot system described in the paper.

Reply to Mr. Job.—The contribution by Mr. Robert Job was of considerable interest, coming as it did from one who had given special study to that question; in fact his recent paper on "Internal Transverse Cracks and Fissures in Rails" was a classic contribution to that important subject. The authors wished there were more work done in the same direction by others. Mr. Job pointed out the logical conclusions in order to improve practice, namely, that unsound steel should be avoided, piping steel used, and that piping properly taken care of, as was the case with the ingots referred to in the present paper, which it should be noted could be guaranteed to be efficacious with just as much certainty in one million as one hundred ingots. One of the authors was quite willing to guarantee that it was as easy to produce ten thousand as a million ingots, every one of which would be found to be perfect before going to the rail mill. In other words, the method enabled sound steel to be obtained with absolute uniformity, and, moreover, by its use imperfect material was detected at its very source—a point of advantage not, to the author's knowledge, possessed by any other system.

Again the authors wished to impress upon those concerned that the essential to success was that each of the following details should be carried out:

(*a*) Large end of ingot cast uppermost.
(*b*) Sand or fireclay head.
(*c*) Insulating slag placed on the top of the molten steel.
(*d*) Charcoal on the surface of the slag—that is, above the slag.
(*e*) Air-blast.

It was no use trying a number of those points and omitting one; they should all be observed concurrently, as was the case with the ingots made by the authors for their research. The extraordinary plan, mentioned by one of the contributors to the discussion, of covering the metal in the head with slag and coke, and employing air under pressure to ignite the coke, should not be adopted.

It did not seem to be sufficiently realised that steel which was in the first place unsound, even though the blowholes might appear to be afterwards welded, was not suitable or safe for rail steel. Such material never gave the same ultimate strength as when made from steel which was in the first place sound and free from blowholes. One of the authors expected shortly to write a paper on that subject and to prove the point thoroughly.

Reply to Mr. Sellew.—The authors were very glad to see the valuable contribution from Mr. W. H. Sellew, whose most excellent book, "Steel Rails," should be read and known by all interested in railroad problems. Mr. Sellew referred to the test of heavy rails of 135 lbs. section. It should, however, be pointed out that beyond reducing the risk of breakage (that was to say, the same area of unsoundness in a large rail would not be felt so much as in a small rail), increasing the size of section would not effect a cure if the material were in the first place unsound. The irregular failure of some of the rails to which Mr. Sellew referred must have originated in defective material; in fact, as ingots were now made, that could not be otherwise. If ingots which were not variable were produced, as was done by the methods described in the paper, the finished products would not vary. That did not mean that all failures would be stopped, because a sound ingot might be overheated or badly rolled and the material spoiled. Nevertheless, the chances of failure were infinitely less when sound steel was in the first place employed for producing such products.

Concluding remarks.—Several of the contributors to the discussion had referred to the fact that the American ingot shown in the paper did not represent English practice. No doubt that was correct. On the other hand, that serious failures did occur in Great Britain with rails was shown by the statement made not long ago to one of the authors by a well-known railway engineer, namely, that one rail per 65 miles of track had to be taken out each year, either owing to fracture or other defect. That was not a very satisfactory state of things.

To show also that "piping" ingots were still being unfortunately turned into rails, Plate XVII. illustrated a bad specimen rail made, not years ago, but within the last few months. To use the words of the engineer in question, Plate XVII. represented "a new rail which luckily did not find its way into the line. It was specially interesting, as the rail appeared to be perfectly sound before being cut." If that rail had gone into service, no doubt it would have caused a very serious disaster, the avoidance of which, as the authors had several times pointed out, could be absolutely ensured by the methods described in the present paper. Could there be a stronger proof of the great desirability of no rail ingot being allowed to go into the rolling mill unless it were known to be sound.

It was satisfactory to know that that matter of sound steel was receiving special attention in America, where the use of steel rails was on such an enormous scale. Quite recently Mr. Gustave Lindenthal of New York read a paper before the New York Railroad Club (May 21, 1915) on "Qualities of Good Steel Rails." That paper was one which should be studied by every one interested in the matter. As one of the authors had long urged and shown, Mr. Lindenthal says:—

> "Towards that first requisite of sound ingots should be directed all efforts at any reasonable cost. Not one of the present specifications for steel rails ensures through its provisions thoroughly sound ingots."

Again,

> "The first requisite of good rails is good steel, and here we must insist upon sound ingots to commence with."

Further,

> "In the present practice, piping and segregation, being at the smaller end of the ingot, pass into the rolls first, are closed up and squeezed into the metal, and lengthened in the rolling to an unknown extent, forming interior seams and defects which cannot be discovered by inspection. Cropping may and may not remove pipes. It is a mere chance and pretence."

Those were, indeed, important statements from an expert, although none too strong. It was, therefore, extraordinary to find that large quantities of steel were still produced which did not answer to nor truly fulfil the description of sound steel, specially when it was seen, from the facts set forth, that such products could be satisfactorily obtained without any difficulty.

The authors wished to point out that only a few days before, on the invitation of Dr. Stratton, Director of the Bureau of Standards of the Department of Commerce, Washington, D.C., representatives of no less than twenty-four railroad systems in America met at the Bureau in order to confer regarding the best method of securing efficient co-operation between the railroads and the Bureau, including amongst the problems studied the testing of material with special reference to the production of high grade steel rails.

That excellent plan showed that America was desirous of paying special attention to that problem, and certainly what was done on the other side of the water ought to be carefully considered here.

In order that members of the Institute might see exactly how the system was carried out, the authors had added the illustrations given in Plates XVIII. and XIX., which showed that it could be put into practice with no more trouble or difficulty than attended the ordinary methods of casting, with the gain and consequent advantages of increased soundness, freedom from segregation, also a large reduction of discard. Such combination of advantages with the increased safety to human life ensured in the not far distant future that all steel would have to be made by methods of that nature. If the authors had helped to bring about that desirable result, they would feel that their labours, as shown by their various researches and papers on the subject now extending over five years, had been well repaid.

The authors had endeavoured to reply fully and frankly to the various contributors to this discussion.

They would, moreover, again point out that at a time like the present, when economy of material was most desirable, the subject was one of unusual importance. As regards the method dealt with in the paper, there was the fact to be borne in mind that some 70,000 tons of ingots made on those lines had been turned out with entire satisfaction both as regards reduced cost and increased quality.

The price of steel rails to-day was £8, 10s. per ton, and might become higher; therefore, every ton of material saved by the avoidance of unnecessary discard was of importance, specially when at the same time sound and better products were obtained.

Whilst the discussion was voluminous, and took up a good deal of space in the *Journal*, in justification it might be pointed out that seeing the saving of millions of tons of steel was involved, and would be effected if the principles described in the paper were followed up, the Institute would, indeed, have done good work in helping on progress in the metallurgical art by allowing those interesting communications to be set forth in the pages of its volumes from which all metallurgists throughout the world had, in the past, derived so much benefit.

[NOTE.—The manuscript of Dr. Burgess' reply to the discussion and correspondence was received while the present volume was at press, and will be reproduced in the next volume of the *Journal*.—EDITOR.]

BRINELL HARDNESS AND TENACITY FACTORS OF A SERIES OF HEAT-TREATED SPECIAL STEELS.

BY ANDREW McWILLIAM, A.R.S.M., D.MET.
(METALLURGICAL INSPECTOR, GOVERNMENT OF INDIA, RAILWAY DEPARTMENT),
AND
ERNEST JEFFERSON BARNES
(ASSOC. IN METALLURGY OF THE UNIVERSITY OF SHEFFIELD).

THE authors formerly presented to the Institute four separate studies of some properties of heat-treated steels. As the Brinell hardness test has been found by many a convenient and valuable aid in dealing with steels for practical purposes, it was felt that the determination of the Brinell hardness numbers of these very carefully heat-treated and tested samples would be of interest, and that a record of them would be useful. It was intended to carry out the determinations on the unstrained portions of the ends of the tensile test-pieces, these portions being about 1 inch in diameter whereas the test-piece itself was 0·564 of an inch. Fresh interests due to the sudden departure of one of the authors to India and the taking up of a new field by the other have prevented the experiments being finished until now. One result has been that the members of the Bessemer series treated in the Brayshaw salt bath in 1908–9, and laid aside just after testing and without special care, have rusted so badly owing to impregnation of the surface with the salts of the bath that the distinguishing numbers and marks are not now decipherable, and this whole series has, therefore, had to be omitted. It is well to remember that after treatment in the salt bath, if samples are to be preserved for any length of time, the salts must be dissolved out by water.

The authors have made a practice of using for examination under the microscope comparatively thick pieces of their steels cut from the unstrained portion of the tensile test-pieces right across the bar and about ¼ inch thick, so that when these are cut again parallel to the axis of the bar but not quite centrally, the whole type of structure on the transverse section and the structure of the longitudinal section may be obtained from the same numbered micro-section. In some cases where a full section of the unstrained portion was not available these micro-sections have been used for the Brinell test, and in a few of the softest samples the outside of the piece was slightly bulged, showing that the piece was too small for the test and the hardness number will be more or less low. All these are marked B. for bulged or S.B. slightly bulged, so that no wrong deductions may be drawn from the figures, which are all recorded. The tests were made on the transverse sections under the usual standard conditions of 3000 kilogrammes pressure on a 10-millimetre ball for 30 seconds.

Treatments with Distinguishing Letters.

TABLE I.

Treatment.	Letter.
As received	None.
Normalised: 900° C. or 950° C. for 30 minutes, and cooled in air	N
Annealed: slowly heated up to 950° C.; kept at 950° C. for about 35 hours; very slowly cooled in furnace	A
Quenched from 800° C. or 850° C. in water, and tempered at 400° C.	Y
,, ,, ,, 550° C.	X
,, ,, ,, 650° C.	T
,, ,, ,, 700° C.	W

2 *per Cent. Chromium Steels.*

TABLE II.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors.	
	Diameter.	Hardness.			Yield Point.	Maximum Stress.
Carbon, 0·20—						
1154	4·90	149	22·8	35·2	0·153	0·236
1154 N	4·98	144	21·0	33·4	0·146	0·236
1154 A	5·35	124	16·0	33·0	0·129	0·266
1154 Y	...	...	67·0	68·6	...	...
1154 X	...	...	55·0	58·0	...	...
1154 W	4·58	172	32·0	41·2	0·186	0·240
					Mean = 0·244	

2 *per Cent. Chromium Steels—continued.*

TABLE III.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors.	
	Diameter.	Hardness.			Yield Point.	Maximum Stress.
Carbon, 0·25—						
1153	4·8	156	24·4	38·6	0·156	0·247
1153 N.	4·83	154	24·0	38·1	0·156	0·247
1153 A.	5·70	107	16·0	35·0	0·150	0·327
1153 Y.	3·15	375	78·3	88·2	0·209	0·235
1153 X.	3·47	307	68·0	72·0	0·221	0·235
1153 W	4·20	207	41·0	48·0	0·198	0·232
				Omitting 1153 A, mean=0·239		
TABLE IV.						
Carbon, 0·32—						
1152	4·50	179	30·0	46·3	0·168	0·26
1152 N.	4·40	187	28·0	45·9	0·150	0·245
1152 A.	5·50	116	14·4	30·4	0·124	0·262
1152 Y.	3·0	418	92·0	100·0	0·219	0·239
1152 X.	3·27	347	75·9	79·6	0·219	0·229
1152 W	3·9	241	47·0	54·8	0·195	0·223
					Mean=0·243	
TABLE V.						
Carbon, 0·50—						
1157	4·30	196	32·0	53·8	0·163	0·274
1157 N.	3·89	242	42·0	61·0	0·174	0·252
1157 A.	4·9	149	12·8	37·6	0·086	0·252
1157 Y.	2·87	454	104·1	112·0	0·229	0·247
1157 X.	3·12	382	85·1	89·6	0·223	0·234
1157 W	...	...	57·0	62·4	...	...
					Mean=0·252	

The factors, maximum stress divided by hardness number and yield point divided by hardness number, are inserted in Tables II. to V. Brinell, Dillner, and others have shown that with normalised samples a fair approximation to the tenacity of a steel may be obtained by multiplying its hardness number by a factor. It is well known, however, that many calculations are for convenience made on the maximum stress that really ought to be made on the yield point or on the elastic limit of the steel, but are nevertheless generally successful in practice because of the fairly consistent relationship between the elastic limit and the maximum stress in steels of the types and sections generally used in important structures. Cases have, however, come under notice where owing to special circumstances the elastic limit is much less than the usual percentage of the maximum stress and trouble has resulted.

It was considered of interest to calculate the factors for both the yield points and maximum stresses in these series since the ratio of yield point to maximum stress varies so very much, namely from less than 50 per cent. to over 95 per cent. Tables II. to V. bring out so clearly with these very varying types of steel that it is really only the maximum stresses and not the yield points that bear any approximately consistent relationship to the hardness numbers, that the factors for the yield points are not given in the tables that follow. Similarly neither do the elastic limits or limits of proportionality show any consistent relationships to the hardness numbers.

2 *per Cent. Chromium Steels—continued.*

TABLE VI.

	Brinell Nos.		Yield Point.	Maximum. Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·65—					
1168 . . .	3·57	290	58·0	71·3	0·246
1168 N . . .	3·52	298	56·0	68·0	0·228
1168 A . . .	4·02	226	32·0	49·9	0·216
1168 Y . . .	...	...	...	...	...
1168 X . . .	3·01	415	94·1	96·5	0·233
1168 W . . .	3·73	265	56·8	62·6	0·236
					Mean=0·232

TABLE VII.

Carbon, 0·85—					
1155 . . .	3·41	319	52·0	75·9	0·238
1155 N . . .	3·75	262	52·0	71·1	0·271
1155 A . . .	4·20	207	18·8	40·1	0·194
1155 Y . . .	...	...	...	...	...
1155 X . . .	3·05	402	92·5	95·7	0·238
1155 W . . .	...	...	57·5	63·0	...
					Mean=0·235

3 *per Cent. Nickel Steels.*

TABLE VIII.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·06—					
1239 . . .	5·50	116	23·0	29·9	0·258
1239 N . . .	5·50	116	21·0	29·7	0·256
1239 A . . .	5·7 S.B.	107	18·4	26·8	0·250
1239 Y . . .	5·0	143	26·4	33·1	0·231
1239 X . . .	5·10	137	23·2	31·7	0·231
1239 T . . .	5·27	127	23·2	31·1	0·245

Mean=0·245

TABLE IX.

Carbon, 0·12—					
1255 . . .	5·38	122	21·0	30·9	0·253
1255 N . . .	5·49	116	21·2	30·1	0·260
1255 A . . .	5·65	109	18·8	27·7	0·254
1255 Y . . .	5.1 B.	137	28·0	35·8	0·261
1255 X . . .	4·85	153	25·0	34·4	0·225
1255 T . . .	5.45 S.B.	118	23·0	32·9	0·279

Omitting 1255 Y and 1255 T, Mean=0·248

TABLE X.

Carbon, 0·28—					
1253 . . .	5·01	142	23·0	35·6	0·251
1253 N . . .	5·02	142	23·0	35·0	0·246
1253 A . . .	5·37	123	21·2	30·4	0·247
1253 Y . . .	4·20	207	36·8	46·6	0·225
1253 X . . .	4·30	196	34·4	45·0	0·230
1253 T . . .	4·65	166	28·4	38·6	0·233

Mean=0·239

TABLE XI.

Carbon, 0·30—					
1256 . . .	4·80	156	23·0	36·0	0·231
1256 N . . .	4·92	148	22·4	36·0	0·243
1256 A . . .	5·4	121	16·8	30·0	0·248
1256 Y . . .	4·05	223	38·4	50·0	0·224
1256 X . . .	4·20	207	36·0	50·4	0·243
1256 T . . .	4·55	174	29·2	40·2	0·231

Mean=0·237

3 *per Cent. Nickel Steels—continued.*

TABLE XII.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·47—					
1254 . . .	4·50	179	25·0	42·6	0·238
1254 N . . .	4·70	163	24·8	41·5	0·254
1254 A . . .	5·17	133	19·2	32·1	0·241
1254 Y . . .	3·69	271	48·8	66·6	0·246
1254 X . . .	3·72	266	42·4	60·4	0·227
1254 T . . .	4·50	179	33·6	47·0	0·263
					Mean=0·245

TABLE XIII.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·67—					
1252 . . .	4·18	209	27·0	51·5	0·246
1252 N . . .	4·10	217	29·0	50·7	0·234
1252 A . . .	5·0	143	21·2	31·4	0·220
1252 Y . . .	3·15	375	79·4	90·8	0·242
1252 X . . .	3·45	311	59·0	74·8	0·241
1252 T . . .	4·0	228	41·0	52·4	0·230
					Mean=0·236

TABLE XIV.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·74—					
1251 . . .	3·85	248	34·0	57·9	0·233
1251 N . . .	3·7	269	31·0	59·2	0·220
1251 A . . .	5·97 S.B.	96	16·4	25·0	0·260
1251 Y . . .	3·0	418	93·2	96·8	0·233
1251 X . . .	3·30	340	69·0	82·4	0·242
1251 T . . .	3·85	248	46·4	56·2	0·227
					Mean=0·236

TABLE XV.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·91—					
1261 . . .	3·6	286	35·0	66·8	0·234
1261 N . . .	3·67	274	34·0	66·6	0·243
1261 A . . .	5·98	96	14·4	23·6	0·246
1261 Y . . .	2·95	430	94·0	105·7	0·246
1261 X . . .	3·14	377	73·6	88·9	0·236
1261 T . . .	3·95	235	47·0	58·2	0·248
					Mean=0·242

0·2 *per Cent. Vanadium Steels.*

TABLE XVI.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·09—					
1241 . . .	4·65	166	33·6	38·1	0·230
1241 N . . .	5·78 S.B.	104	17·6	25·1	0·241
1241 A . . .	6·4 B.	82	13·2	23·0	...
1241 Y . . .	5·50	116	18·4	27·1	0·234
1241 X . . .	5·40	121	20·0	30·8	0·255
1241 W . . .	5·50	116	20·0	18·1	0·242
					Mean=0·240

TABLE XVII.

Carbon, 0·23—					
1240 . . .	5·0 S.B.	143	29·6	40·5	0·283
1240 N . . .	5·3 S.B.	126	21·2	32·0	0·254
1240 A . . .	6·05 V.S.B.	94	12·4	25·4	0·270
1240 Y . . .	4·78	157	26·0	38·0	0·242
1240 X . . .	4·75	159	26·4	39·3	0·247
1240 W . . .	4·97	145	24·8	35·7	0·246
	Omitting the three bulged samples, Mean=0·245				

TABLE XVIII.

Carbon, 0·40—					
1238 . . .	4·0	228	39·0	53·7	0·236
1238 N . . .	4·3	196	29·2	42·4	0·216
1238 A . . .	5·42	120	16·4	30·8	0·257
1238 Y . . .	3·94	236	45·0	56·8	0·241
1238 X . . .	4·01	227	40·4	54·2	0·239
1238 W . . .	4·31	195	35·2	45·9	0·235
					Mean=0·237

TABLE XIX.

Carbon, 0·56—					
1235 . . .	3·82	252	39·0	59·5	0·236
1235 N . . .	4·25	202	29·2	46·0	0·228
1235 A . . .	5·11	136	14·4	35·1	0·258
1235 Y . . .	3·6	286	51·0	66·6	0·233
1235 X . . .	3·72	266	47·0	60·7	0·228
1235 W . . .	4·15	212	36·0	50·2	0·237
					Mean=0·237

0·2 *per Cent. Vanadium Steels—continued.*

TABLE XX.

	Brinell Nos.		Yield Point.	Maximum Stress.	Factors, Maximum Stress.
	Diameter.	Hardness.			
Carbon, 0·71—					
1263 . . .	3·56	292	44·0	70·4	0·241
1263 N . . .	3·83	251	30·0	54·7	0·218
1263 A . . .	4·67	165	17·0	41·3	0·250
1263 Y . . .	3·30	340	66·0	83·2	0·245
1263 X . . .	3·40	321	57·6	79·5	0·248
1263 W . . .	3·90	241	41·0	56·4	0·234
					Mean=0·239

TABLE XXI.

Carbon, 0· —					
1260 . . .	3·42	317	39·0	69·6	0·220
1260 N . . .	3·55	293	31·0	64·0	0·218
1260 A . . .	4·68	164	16·0	40·1	0·244
1260 Y . . .	3·15	375	71·2	93·0	0·248
1260 X . . .	3·21	361	64·0	90·3	0·250
1260 W . . .	3·80	255	42·0	60·3	0·236
					Mean=0·236

TABLE XXII.

Carbon, 1·32—					
1234 . . .	3·53	297	38·0	66·4	0·224
1234 N . . .	3·80	255	28·8	52·8	0·207
1234 A . . .	4·79	157	16·0	37·7	0·240
1234 Y . . .	...	...	76·0	92·7	...
1234 X . . .	...	...	57·0	85·4	...
1234 W . . .	3·8	255	40·0	60·9	0·239
					Mean=0·228

For convenience of reference the means of the results for the several treatments of the different series of steels are given omitting bulged samples and the few abnormal results which the authors are not in a position to repeat.

Samples as Received.

			Mean.
2 per cent.	Chromium,	0·236, 0·247, 0·260, 0·274, 0·246, 0·238	. 0·250
3 ,, ,,	Nickel,	0·258, 0·253, 0·251, 0·231, 0·238, 0·246, 0·233, 0·234	. 0·243
0·2 ,, ,,	Vanadium,	0·230, 0·236, 0·236, 0·241, 0·220, 0·224	. 0·231

Normalised Samples.

			Mean.
2 per cent.	Chromium,	0·236, 0·247, 0·245, 0·252, 0·228, 0·271	0·246
3 ,, ,,	Nickel,	0·256, 0·260, 0·246, 0·243, 0·254, 0·234, 0·220, 0·243	0·244
0·2 ,, ,,	Vanadium,	0·241, 0·216, 0·228, 0·218, 0·218, 0·207	0·221

Drastically Annealed Samples.

2 per cent.	Chromium,	0·266, 0·262, 0·252, 0·216	0·249
3 ,, ,,	Nickel,	0·250, 0·254, 0·247, 0·248, 0·241, 0·220, 0·260, 0·246	0·246
0·2 ,, ,,	Vanadium,	0·257, 0·258, 0·250, 0·244, 0·240	0·250

Y Treated Samples.

2 per cent.	Chromium,	0·235, 0·239, 0·247	0·240
3 ,, ,,	Nickel,	0·231, 0·261, 0·225, 0·224, 0·246, 0·242, 0·233, 0·246	0·238
0·2 ,, ,,	Vanadium,	0·234, 0·242, 0·241, 0·233, 0·245, 0·248	0·240

X Treated Samples.

2 per cent.	Chromium,	0·235, 0·229, 0·234, 0·233, 0·238	0·234
3 ,, ,,	Nickel,	0·231, 0·225, 0·230, 0·243, 0·227, 0·241, 0·242, 0·236	0·234
0·2 ,, ,,	Vanadium,	0·255, 0·247, 0·239, 0·228, 0·248, 0·250	0·244

T or W Treated Samples.

2 per cent.	Chromium,	0·240, 0·232, 0·223, 0·236	0·233
3 ,, ,,	Nickel,	0·245, 0·233, 0·231, 0·263, 0·230, 0·227, 0·248	0·240
0·2 ,, ,,	Vanadium,	0·242, 0·246, 0·235, 0·237, 0·234, 0·236, 0·239	0·238

CHROMIUM SERIES.

Steels of less than 50 Tons Maximum Stress.

0·236, 0·236, 0·240, 0·247, 0·247, 0·232, 0·260, 0·245	0·243

Steels of 50 Tons Maximum Stress and over.

0·235, 0·235, 0·239, 0·229, 0·223, 0·274, 0·252, 0·247, 0·234, 0·246, 0·228, 0·233, 0·236, 0·238, 0·271, 0·238	0·241
Grand mean of chromium steels	0·242

NICKEL SERIES.

Steels of less than 50 Tons Maximum Stress.

0·258, 0·256, 0·231, 0·231, 0·245, 0·253, 0·260, 0·225, 0·251, 0·246, 0·225, 0·230, 0·233, 0·231, 0·243, 0·231, 0·238, 0·254, 0·263	0·242

Steels of 50 Tons Maximum Stress and over.

0·224, 0·243, 0·246, 0·227, 0·246, 0·234, 0·242, 0·241, 0·230, 0·233, 0·220, 0·233, 0·242, 0·227, 0·234, 0·243, 0·246, 0·236, 0·248	0·237
Grand mean of nickel steels	0·239

VANADIUM SERIES.

	Mean.
Steels of less than 50 Tons Maximum Stress.	
0·230, 0·234, 0·242, 0·242, 0·247, 0·246, 0·216, 0·235, 0·228	0·238
Steels of 50 Tons Maximum Stress and over.	
0·236, 0·233, 0·228, 0·237, 0·236, 0·241, 0·239, 0·241, 0·218, 0·245, 0·248, 0·234, 0·220, 0·218, 0·248, 0·250, 0·236, 0·220, 0·207, 0·239	0·234
Grand mean for vanadium steels	0·235

The fair consistency of the factors in steels varying from 24 to 112 tons per square inch tenacity with yield points from 50 to 95 per cent. of the maximum stress, and for such varying compositions and heat treatments, indicates that for any type of composition and heat treatment of steel a few preliminary experiments would determine a factor by means of which a close approximation to the tenacities of similar steels could be calculated from the Brinell hardness numbers.

For comparison the results of experiments made by one of the authors on a series of fourteen mild steels may be cited. The series varied in tenacity from 23·0 to 31·4 tons per square inch. The steels were all tested for Brinell hardness "B" and on two different types of tensile testing machines A and C, and results were also calculated from an empirical formula D. The greatest difference between the A and B results was 1·3 ton, and the least 0·0 ton, and the means of the A, B, C, and D results were 28·11, 28·56, 28·39, 28·01 respectively.

All the above calculations were made in the midst of an Indian jungle to the accompaniment of the threatening note of the mosquito and the wild howls of jackals, so suggestive of hostile criticism, that all the figures were doubly checked.

DISCUSSION.

Professor C. A. **Edwards** (Manchester University), in opening the discussion, said he was particularly interested in the paper because it dealt with the variation of Brinell ball hardness according to the varying heat treatment of steels. The remarks he had to make were not in the nature of criticism, but he thought they were of sufficient interest and importance to warrant very careful consideration. In some experiments that Mr. Kikkawa had been conducting in his (Dr. Edwards') laboratory, it had been found that, on heating certain chromium steel in the annealed state to varying temperatures and cooling the specimens in air, a variation was obtained in the Brinell ball hardness according to the following curve, in which the vertical ordinates represented hardness and the horizontal ordinates represented temperatures. The specimens were 1 cubic inch in size. They were heated to the indicated temperatures for an hour, and then taken out of the furnace and allowed to cool in a normal manner on an asbestos bed. In the annealed state the hardness of the steel was somewhere about 273. On heating it to about 730°, and cooling, no variation of hardness occurred, but the moment that critical point of heating was passed, the hardness began to increase proportionately with the initial temperature according to the line BC (Fig. 1*a*). That was not obtained by any means of quenching, as quenching was usually understood, but by natural cooling. The hardness was as great as the hardness of a quenched carbon steel, namely, well over 700. Without dwelling on the theoretical significance of that fact, a point which he knew Professor Carpenter was particularly interested in, he was able to reconcile some of the previous apparent divergence of opinion that existed; and it indicated that in the steel in question, although the cooling was slow, the particular rate really resolved itself into a quenching; that, in other words, chromium steel was a self-hardening steel. He had found that the self-hardening property of chromium tungsten steels was not due to tungsten; it was due to chromium. In other words, members would appreciate what he meant when he said that if Mushet had worked with pure tungsten steels he would not have discovered the self-hardening Mushet steel. All Mushet's steel contained either manganese or chromium. He desired particularly to emphasize what he might describe as the critical cooling velocities of the chromium steels. Very careful cooling curves had been taken under different rates, and it was found that if a chromium steel containing 6 per cent. of chromium was cooled from 1200° C. down to 400° C., and that cooling took 35 minutes, a critical point like that shown in curve No. 1, Fig. 2*a*, was obtained at about 740°. If it took 25 minutes to cool over the same range, curve No. 2 would be obtained,

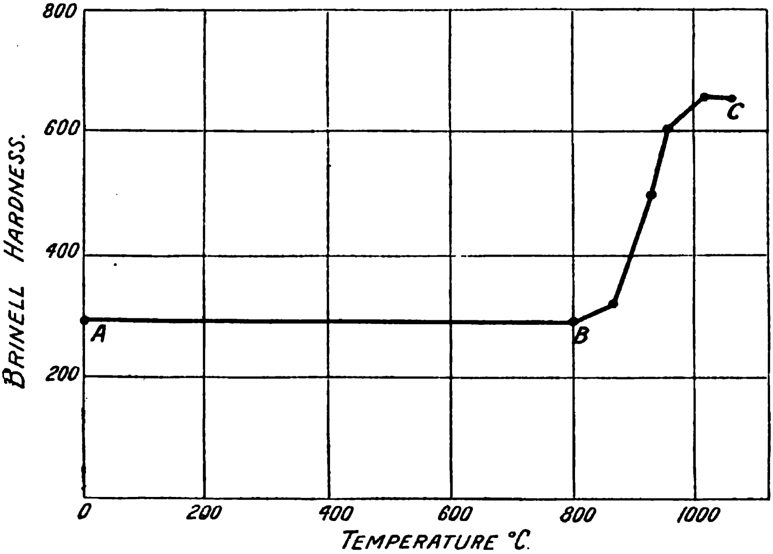

800
600
400
200
BRINELL HARDNESS.
A
B
C
0
200
400
600
800
1000
TEMPERATURE °C.

FIG. 1*a*.

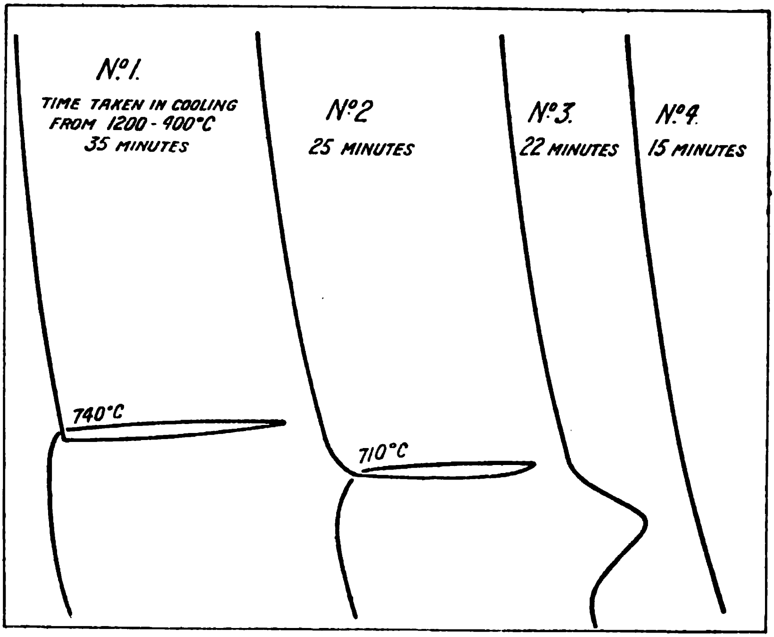

Nº1.
TIME TAKEN IN COOLING FROM 1200 - 400°C 35 MINUTES
Nº2
25 MINUTES
Nº3.
22 MINUTES
Nº4.
15 MINUTES
740°C
710°C

FIG. 2*a*.

while on cooling for about 22 minutes a depression something like curve No. 3 was obtained. If the cooling took 15 minutes, no point at all was obtained (curve No. 4). That indicated that under that cooling rate of 15 minutes, which was a mild kind of quenching, the carbide critical point was completely suppressed, and hardening was obtained; and the steel was martensitic, according to Professor Carpenter's and his own view, as a result of the internal working caused by the external pressures. He proposed, with the permission of the Council, to present, along with Mr. Kikkawa, the results of their investigations at the next meeting of the Institute in the form of a somewhat extensive paper. He thought the experiments showed that by taking the cooling velocities of any steel in a laboratory, by determining the position at which those critical points occurred under different rates of cooling, it was possible to control in the laboratory any property of these particular kinds of steels for any given heat treatment. For instance, if it were desired to make a shell of a certain hardness, and the critical period to produce that hardness were known in the laboratory, all that it was necessary to do was so to adapt the quenching medium that it would give that quenching velocity, and the particular hardness indicated in the laboratory would then be obtained. The remarks he had made were not directly connected with the paper, but as they were of very great practical importance and of far-reaching theoretical significance, he thought they were not altogether without bearing upon the subject with which the paper dealt.

Professor **McWilliam** inquired whether there was any carbon in the steel to which Dr. Edwards referred.

Dr. **Edwards** replied that the percentage of carbon was 0·63, and the chromium 6 per cent.

Professor H. **Le Chatelier**, Member of Council, said he was pleased to meet once again with a confirmation of the view respecting the strict proportionality which obtained between the Brinell hardness number and the tensile strength, even in the case of special chromium, nickel, and vanadium steels. In his opinion, the most important point in the research was the removal beyond all possibility of doubt of the non-proportionality between the hardness number and the elastic limit of the metal. That absence of proportionality had been known for a long time past, but it would appear that it was too often forgotten to take it into account. At the present time the control of the manufacture of projectiles was often checked by means of the Brinell hardness number. As for that purpose only the elastic limit of the metal was taken into consideration, it might be asked why the measurement of the hardness supplied useful indications as to the nature of the metal? It could only do so on the condition that the whole of the processes of manufacture were carried out strictly by predetermined rules, and by having regard to the constancy of the chemical composition of the metal, the temperatures of hardening and the temperatures of annealing. If all those conditions were fulfilled, as well as those relating to the hardness, it would necessarily result that the elastic limit itself would remain constant. If, however, the nature of the metal were changed at the same time as the conditions of hardening, so as to preserve only the hardness number, such a test would have no value whatever. The same tensile strength would certainly always be obtained, but not the same elastic limit, which was the only factor of importance.

Dr. J. E. **Stead**, Vice-President, said he was sure all members of the Institute welcomed the return of Mr. McWilliam from India. The paper was a most valuable one, not only because it gave the results of research leading to the determination of factors for calculating the tenacity and yield points when using the Brinell method of testing, but on account of the information it contained regarding the physical properties of a variety of steels in their normal and heat-treated condition.

The work of the authors was most useful in view of the fact that the Brinell testing machine had found its way into the most progressive iron, steel, and engineering works in this country. If he might make a suggestion, he thought it would increase the usefulness of the paper if a summary of the previous work on carbon steels were introduced and published with the present paper.

Dr. **Walter Rosenhain**, F.R.S. (Teddington), desired to refer to one point only, namely, the question of the relationship of the Brinell hardness number to the elastic limit or yield point, as compared with its relationship to the ultimate stress. It would obviously be wrong to attempt to utilise the Brinell test by itself as an investigatory test for exploring new materials, because there was a great deal to be said for the utilisation of the elastic limit or yield point rather than the ultimate stress when the practical value of the material was under consideration. As one who had always strongly upheld the importance of that particular test, he thought it right to make it clear that that did not in the least invalidate the use of the Brinell method for very many important practical purposes, and still less would he depreciate in any way the value of the correlation between tensile stress and Brinell number, with which the paper so successfully dealt. Where the Brinell test was used as a routine test, as in the case cited by Professor Le Chatelier in connection with shell-making, a comparison was being made of the properties of successive batches of the same material or similar materials which had been, in general terms, similarly treated, and there the co-ordination of the elastic limit or the yield point was amply sufficient for all practical purposes, so that even an ardent supporter of the elastic limit or the yield point as the vital factor need be no opponent of the Brinell method.

Professor McWilliam said, in reply, that Dr. Rosenhain had very well brought out the point that with a similar material under similar circumstances only the maximum stress was obtained, but there was one point that should be remembered, namely, that under very similar conditions the yield point and the elastic limit followed in the former's wake. He would not say that he thoroughly agreed with all the remarks that had been made, because some of them had been too complimentary, but he thanked the members for the kind remarks they had made, and especially Dr. Edwards for having given details of such an important and interesting series of experiments.

The Chairman, in moving a hearty vote of thanks to the authors for their interesting and instructive paper, said he desired in the fullest possible manner to associate himself with the remarks that had been made heartily welcoming Mr. McWilliam back again to England from India.

IRON, CARBON, AND PHOSPHORUS.

By J. E. STEAD, D.Sc., D.Met., F.R.S., Vice-President.

Since I presented my paper on "Iron and Phosphorus" (28) * to this Institute in 1900, I have not ceased to study the alloys of iron, phosphorus, and carbon, and have published some of the results of my investigations in papers and lectures given before several Societies, a tabulated list of which will be found in the bibliography at the end of the present paper.

By way of introduction it is necessary briefly to review what has previously been published of late years.

SECTION I.

Introduction.

The only paper of importance presented to the Iron and Steel Institute since 1900 dealing with the alloys of iron and phosphorus is one by Saklatwalla (41) on the constitution of iron-phosphorus compounds. The paper was accompanied by an equilibrium diagram, which is here reproduced.

The investigations of that gentleman confirm the more important work that I had previously published. He found that the saturated solid solution of phosphorus in iron approximated to 1·75 per cent. phosphorus and 98·25 per cent. iron, and that the eutectic contained a little over 10 per cent. phosphorus. I had obtained 980° C. as the freezing point of the eutectic against a little over 1000° C., a figure which more recent trials have confirmed. Mr. Saklatwalla discovered a second eutectic, consisting of crystals of Fe_2P and Fe_3P, which I had not observed, but I had separated the juxtaposed crystals and determined their composition by analysis.

He found arrests in cooling the alloys containing between 8 and 6·5 per cent. phosphorus, which led him to draw the

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* The small numerals refer to the Bibliography at end of paper.

curve Q R on the diagram, and to suggest either that the eutectic changed in composition or that some mysterious physical changes occurred. In my experience I have found that the eutectic has the same melting point whether there is 2 per cent. or 10 per cent. of phosphorus, and that the line S Q R is straight and not curved as shown.

Saklatwalla found Fe_3P to have a hardness of No. 6 on Mohr's scale, corresponding with that of felspar.

It was during 1875–6–7 (9) that the first serious effort was made to determine the composition of the last portions that remained liquid in slowly solidifying grey Cleveland iron. This was done by subjecting the solidifying metal to hydraulic pressure, and submitting to analysis the last portion expressed. At that early date, about forty years ago, little or nothing was known in the iron and steel world of the important compound constituents of many alloys called "eutectics"; but, as the later researches have proved, the substance I actually squeezed out of Cleveland iron consisted of almost pure ternary eutectic of iron-phosphorus-carbon, the microstructure of which I described in 1900, and more recently in 1914 (42).

Allowing for the displacement of a certain amount of carbon by the silicon present in the final liquid portion, the calculated composition of the pure eutectic was arrived at. Professors Wüst and Goerens (25, 26) afterwards synthetically prepared the pure substance, and their analyses, together with the adjusted analysis of the substance I obtained, are as follows:—

	Stead.	Wüst.	Goerens.
	Per Cent.	Per Cent.	Per Cent.
Iron . . .	91·19	91·30	91·15
Carbon . .	1·92	2·00	1·96
Phosphorus .	6·89	6·70	6·86

It was indicated in 1900 (28) that while the eutectic present in very grey phosphorettic metals consisted of the binary eutectic containing about 10 per cent. phosphorus and 90 per cent. iron, it was the ternary eutectic which is always present

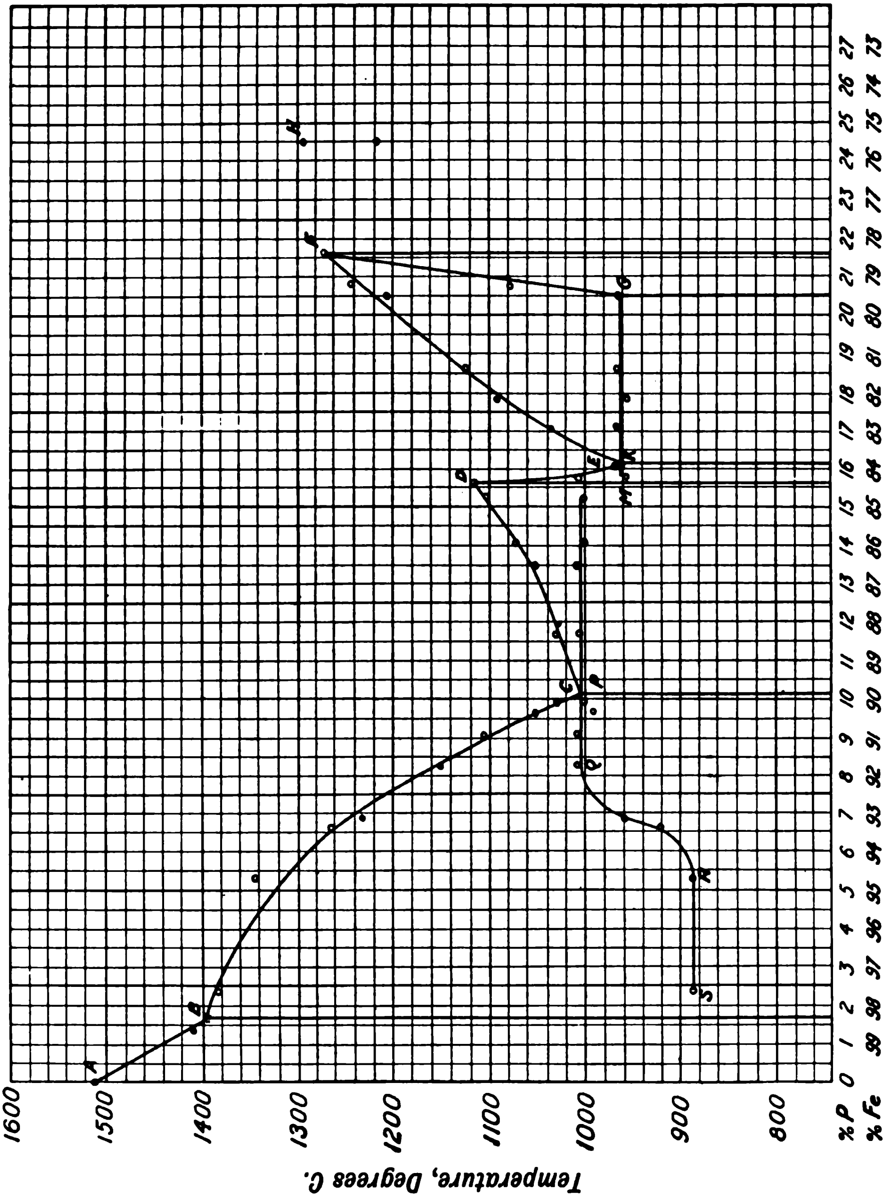

Temperature, Degrees C.
1600
1500
1400
1300
1200
1100
1000
900
800
% P
% Fe
0
1 99
2 98
3 97
4 96
5 95
6 94
7 93
8 92
9 91
10 90
11 89
12 88
13 87
14 86
15 85
16 84
17 83
18 82
19 81
20 80
21 79
22 78
23 77
24 76
25 75
26 74
27 73
A
B
C
D
E
F
G
H
K
P
Q
R
S
W

FIG. 1.

in white and mottled iron. It was also proved that practically all the phosphorus in grey pig irons, even when the amount was as low as 0·04 per cent. and less, was concentrated in independent patches of the ternary eutectic.

Later, Professor Carpenter ([33]) proved that the arrests during the solidification of the eutectic in very grey and white Cleveland irons were identical at 945° C. with the freezing point of the ternary eutectic, a result closely confirming that of Goerens and others ([23, 24, 25, 26]). This important result, proving that the triple eutectic is that which first forms, confirmed what I had previously obtained by squeezing out this very portion from grey Cleveland iron. It is after complete solidification of the ternary eutectic that the carbon diffuses out of it, for it is the binary eutectic that remains in the cold grey metal from which a portion of the ternary eutectic has been removed by pressure.

In my early attempt to remove phosphorus from iron by pressure, it was only a mere fraction of the total amount of the eutectic that was actually squeezed out of the metal, for the simple reason that the metal in the mould could not be maintained throughout at 945° C. Theoretically, could this have been possible, a complete separation of practically all the phosphorus should, with the pressure sufficient, have been attained.

The sequel to my experiment has been afforded by the "bear" of one of the Skinningrove furnaces ([42–46]). The large mass of metal, about 500 or 600 tons in weight, in cooling exceedingly slowly, contracted circumferentially and compressed the central portion, which, being in the middle, was the last completely to solidify. The effect of this enormous pressure caused the central plastic mass to assume a vertical column, an arrangement closely resembling on a small scale the basalt of Giant's Causeway. These columns could be more or less readily separated from one another.

The analyses of one portion of the formation were as follows:—

	Probable Composition of the Original Cleveland Iron.	Central Column.
	Per Cent.	Per Cent.
Iron	92·34	93·400
Combined carbon	0·50	0·562
Graphite	3·00	1·640
Manganese	0·70	0·173
Silicon	1·80	1·166
Sulphur	0·10	0·103
Phosphorus	1·56	0·155
Oxygen, &c.	...	2·801
	100·00	100·000

Phosphorus expressed probably about 90 per cent.

The eutectic had evidently escaped vertically between the columns during the period of extreme pressure. That a little (0·155 per cent.) remained is not surprising, because a portion of the liquid was bound to have been trapped mechanically in the metal itself. It may be accepted, therefore, that the conclusion previously arrived at is correct, and that the whole of the phosphorus in highly carburised irons is concentrated in the last portions to solidify.

(In a paper read before the Cleveland Institution of Engineers in 1897, previous to my later researches, I incorrectly described the phosphide of iron in grey iron as carbide, a mistake made also by many other metallographers.)

A research published by Goerens and Gutowsky (26) on the formation of graphite in pig iron when cooling is of the greatest importance. They conclude, as do Wüst and others, including myself:—

(*a*) That the formation of the graphite which remains in the solid iron occurs during the solidification process.

(*b*) That it occurs only after the previous separation of the eutectic cementite, and that graphite in pig iron is a disintegration product.

(*c*) That the graphite plates become coarser the slower their formation, and more copious the slower the eutectic interval is traversed.

They state that each 1 per cent. phosphorus in pig iron reduces the initial melting point by about 27° C.

These conclusions practically coincide with the careful observations of practical metallurgists made long before the more refined methods of research were available. It had long been noticed that if the cooling of cast iron be accelerated—as it is in making chilled rolls—the carbides of iron first to form remain undecomposed in the chilled outer layer, and that below the chill, where the cooling is slower, graphite plates appear which increase in size with the distance from the chilled surface, and that the graphite plates are smaller in thin than in large castings—due to the less rapid cooling in the former as compared with the latter.

Although these remarks applied to non-phosphorettic iron, they equally apply to phosphorettic pig irons. It is for that reason they are here referred to.

As the structure of the ternary eutectic Fe-C-P was imperfectly illustrated in my original paper, I have introduced a better photograph after heating the alloy to the point when the iron part passed through all the colours to nearly white, the iron phosphide to heliotrope, and the iron carbide to red. (See photograph No. 1, Plate XXI.)

It was shown in 1900 (28) that when the carbon did not exceed 1 per cent. and the amount of phosphorus varied between 0·09 and 0·25 per cent., the microscope revealed concentrations of phosphorus between the crystals, but that only a minute part of the whole existed as free phosphide.

In a later paper on "Crystallisation and Segregation in Steel Ingots," 1906 (31–34), it was shown that the parts of iron and steel richer in phosphorus were relatively slowly attacked by very dilute acid reagents compared with the parts containing less, and by this means the primary fir-tree crystallites were shown to be freer from phosphorus than the parts surrounding them. By the application of this method it was easy to trace portions richer in phosphorus, in any steel whether cast, rolled, or forged. During the solidification of steel containing appreciable amounts of carbon, it was shown that the first crystallites to form were practically free from phosphorus, and that the last portions to freeze contained concentrated in them a greater part of the phosphorus.

It is well known that the outer walls of steel ingots contain less phosphorus than the average of the whole ingot (^{31}), and it is not improbable that this is in consequence of the crystallites growing vertically from the cold sides of the ingot mould in close and massed formation. I have explained this (^{31}) and suggested that the more fusible portions, richest in phosphorus and sulphur, are driven forward where they join the liquid metal within the solid envelope.

As the crystals which form near the chilled surfaces of iron ingot moulds are closely packed together and very numerous, the inclusions of the last parts to become solid are very perfectly distributed and in fine particles; as a consequence inter-diffusion soon after solidification is facilitated with the result that these chilled portions are the most homogeneous of any part of the ingot. That such is the case is confirmed by the newer methods of etching described in Section III.

When the steel freezes (^{34}) in the interior mass of an ingot, separate crystallites develop independently at different centres and attract iron to themselves from the liquid which thus becomes increasingly rich in metalloids. As the crystallites develop branches in three directions at right angles to each other, they eventually surround some of the impure liquid, which, being trapped, is fixed inside the solid crystals.

In steel forgings of average size I have failed to find in the primary crystallites portions rich in phosphorus, but we know that these could not have been homogeneous at the time of their development, and that although it has not been possible to detect them, they are there. Indeed, they are present in exceedingly large crystallites obtained from contraction cavities in large ingots, as was shown in the paper last referred to. Photograph No. 3, Plate XXIV., is from one of these crystallites after etching with the alcoholic cupric reagent.

When separate crystallites grow towards each other (^{31}), that part of the increasingly impure liquid not trapped by the branches of the crystallites is driven forward and is finally imprisoned at their junctions where they solidify.

When blowhole cavities (^{46}) are formed in plastic steel, these, due to internal pressure in the ingot mould, become more or less completely filled with a portion of the impure liquid which is rich in phosphorus and sulphur.

The photographs 4 and 5, Plate XXIII., reproduced in colour from the heat-tinted specimens, represent a partially filled blowhole and a blowhole segregation after the ingot was rolled into a billet.

The upper central axes of steel ingots frequently contain a concentration of the more fusible impure parts of the metal. The amount of this concentration appears to depend on whether or not the steel gives off gas during solidification (31).

Mr. B. Talbot (55) in a most valuable paper published in 1905, on "Segregation in Steel Ingots," proved that 0·007 per cent. of aluminium added to ingots produced soundness and greatly reduced axial segregation. This was fully confirmed by Dr. A. Cooper with the assistance of Mr. C. H. Ridsdale, who kindly cast for me two ingots from a rather wild charge, to one of which was added a little aluminium. That treated with aluminium was quiet in the moulds and gave off no gas; the other was wild and much gas came off during solidification. The latter was axially segregated and also contained blowhole segregations. The non-gaseous ingot was but slightly segregated, and was free from any blowhole segregations.

As nobody appears to have attempted to explain why aluminium, as well as silicon and titanium, check segregation, I have advanced purely hypothetical reasons for this on the basis that the formation of blowholes (46), in a plastic mass, compresses the surrounding steel, squeezing out the more fusible impure liquid portion; this passes towards the centre of the ingot and escapes inside the solidifying walls, and being specifically lighter ascends towards the top of the ingot and is assisted upwards by the bubbles of gas which also ascend. When the ingot top is plated down and becomes solid, the gases, now unable to escape, exert great pressure, greater pressure than that of the gas imprisoned in the blowholes, consequently some of the impure liquid in the plastic walls facing the ends of the blowholes is forced into them until the gaseous pressure within and in the centre of the ingot is equalised.

Phosphorus, according to the researches of Dr. Arnold and others, including myself, when present in carbon steels, raises the critical point A_1.

It is obvious, therefore, that at 1000° C., if the phosphorus be unequally distributed, the critical arrest A_1 will, in cooling down, occur at separate points—in other words, pearlite will form at a higher temperature in the more phosphorised portions than in the parts where the phosphorus is lower.

I have demonstrated beyond any doubt that this does occur, and also, what is more important, that in the steels containing 0·45 per cent. and less carbon, although the carbon may be equally distributed when the steel is at 1000° C., on very slow cooling, the ferrite first appears in the parts richest in phosphorus. The portions which are partially saturated with phosphorus cannot so readily hold in solid solution at certain temperatures as much carbon as the surrounding portions which contain little or no phosphorus, consequently when, in cooling, it reaches these temperatures, the carbon diffuses out of the phosphorised parts into the surrounding purer metal.

This leaves the phosphorus areas free from carbon, and these in large forgings constitute what the workmen call "ghosts" or "phantoms."

The same kind of lines, microscopically small, are for convenience called "Micro-Ghost lines" (^{57}).

As sulphides and phosphides always segregate together, the sulphide inclusions are almost always found in the ghost lines.

It was the association of the sulphides and ferrite that misled Ziegler (^{45}) into making his hypothesis, that it was slag inclusions in steel which induced the ferrite to crystallise round them, just as a disturbance of the surface of a window pane by a scratch induces hoar frost to crystallise in advance round the scratch.

Ziegler's results were obtained by experimenting on rather highly phosphorised steels, which, for reasons given above, were not suitable as the foundations of such a broad generalisation. To show that foreign matter, which is quite free from oxidising elements, does not, at least as a rule, induce ferrite to crystallise round it, it is only necessary to examine mildly carburised cemented Swedish bars, which are practically free from phosphorus, and have been cooled exceedingly slowly in the cementation furnace, for in these the slag inclusions are found to pass through both pearlite and ferrite indiscriminately, and not through the ferrite alone. An example of this is shown in photos 6 and 7, Plate XXIV.

Malleable castings made from hæmatite pig iron contain sulphide inclusions which separate and become solid before the phosphorus eutectic, and as these are not associated with phosphorus in the solid iron, they are found in both ferrite and pearlite.

Further, by mechanically fixing pure silica inclusions in mild pure medium steels, on heating to 1000° C. and slowly cooling, the ferrite in the cold steel is not then found in the form of borders round the silica.

In the many hundreds of ghost lines in commercial forgings I have examined, phosphorus has been concentrated, sometimes in the complete absence of slag or sulphide inclusions. Mr. Harry Brearley, however, in a private letter informs me that on introducing slag into steel, after drastic annealing he has found the slag surrounded by ferrite, a result which appeared to justify Ziegler's conclusion. I am satisfied, however, that such a case is quite exceptional. One undisputable and established law is that the micro-ghost lines in steel bars increase in number and extent with rising phosphorus.

I have found (85) that if steel be maintained at temperatures just below the solidus line, the point of incipient fusion, the phosphorus will gradually diffuse and become equally distributed throughout the mass, and the carbon will also be more equally distributed when the steel is cold. This is not a practical method of producing uniformity, for heating to such high temperatures is very wasteful and is liable accidentally to be exceeded.

At the ordinary temperatures employed for reheating steel for forging and rolling into rails, billets, sheets, &c., phosphorus does diffuse, but at a very slow rate.

Unless the phosphorus be segregated to an excessive extent, on reheating steels, the carbon diffuses into the portions rich in phosphorus, but the temperature required to complete the diffusion is the higher, the greater the phosphorus. For instance, if two steels be taken, one containing

0·06 per cent. and the other 0·005 per cent. of phosphorus, and each containing about 0·3 per cent. carbon, complete diffusion of the carbon will be effected by heating to about 800° C. in the case of the purer steel, but a temperature of about 30° C. greater is necessary to obtain the same result with the less pure steel. By heating and quenching the two steels at definite and increasing temperatures, and examining the etched specimens under the microscope, it can be seen that it is usually the thick ferrite envelopes of the less pure steel that are the last to be invaded by the carbon. It is evident then from this that in heating to refine, one must use higher temperatures for the steels highest in phosphorus. This point of great practical importance is further dealt with in Section II.

Cast-steel founders on "heat-treating" their castings, which usually contain from 0·04 to 0·06 per cent. phosphorus, always raise the temperature well above what is indicated as necessary on the equilibrium iron-carbon diagram of pure iron-carbon alloys. If a steel casting, built up of ferrite-pearlite conglomerate surrounded by thick phosphorised ferrite envelopes, be heated up until the whole of the envelopes have been invaded by diffusing carbon, and be then allowed to cool down very slowly in the furnace, the thick ferrite envelopes will reappear in their original positions, for, as before stated, in low and medium carbon steels, the carbon always first leaves the parts which are highest in phosphorus on slow cooling. It is easy to prove this, for the sulphides which do not diffuse are always associated with the phosphides, and remain fixed no matter what the heat treatment. They are present in the thick envelopes before heating, and are in the same position in the casting after heating and slow cooling. This is clearly shown in photographs No. 8 (*a*, *b*, *c*, *d*), Plate XXV.

(*a*) Steel test-piece annealed and passed as satisfactory.
(*b*) The same as (*a*) after heating to 950° C. and slowly cooling.
(*c*) The same as (*a*) after heating to 950° C. and cooling in 10 minutes.
(*d*) The same as (*a*) after heating to 950° C. and quenching.

As I have recently given a description of the several methods for the detection of the parts richer in phosphorus, I need not here traverse the same ground a second time, so have described in Section III. (30–49) the most recent reagent which has been found to be suitable for developing both the macro- and micro-structure of steels and irons containing phosphorus.

For years I had endeavoured to obtain some means of clearly showing to the eye the imperfect distribution of phosphorus in steel, and have succeeded at last in developing a method whereby the least variation in the amount of phosphorus in any iron or steel can be made visible.

On the Mechanical Properties of Phosphorettic Carbon Steels.

In discussing the Eighth Report of the Alloys Research Committee in 1907 (50), I referred to the mechanical properties of phosphorettic carbon steels, and gave a series of tests showing the influence of phosphorus.

The alloys were kindly prepared for me by Mr. W. Shaw of the Wellington Cast Steel Foundry, Middlesbrough.

A set of three sand moulds 6 inches by 6 inches by 6 inches having been prepared, a ladle of normal casting steel was conveyed from an open-hearth furnace and one of the moulds was filled. To the steel remaining in the ladle sticks of phosphorus were added and the metal well stirred to effect perfect mixture. A second mould was then filled.

The third mould was filled after adding more phosphorus to the steel left in the ladle. In this way a series of steels was obtained identical in all respects excepting in the phosphorus content. The carbon was 0·30 per cent. in each and the phosphorus as follows:—

	Per Cent.
First normal casting	0·04
Second normal casting, with first addition of phosphorus . .	0·30
Third normal casting, with second addition of phosphorus . .	0·50

The castings were sawn in half, one half of each was forged to bars, and these were tested for—

(*a*) Tensile strength.
(*b*) Resistance to shock tests.
(*c*) ,, ,, alternation of stress by the Wöhler method.
(*d*) ,, ,, ,, ,, strain tests.
(*e*) ,, ,, ,, ,, slow bend tests.

COMPARATIVE TESTS ON STEEL CONTAINING VARYING AMOUNTS OF PHOSPHORUS.

Tensile Tests.

No.	Phosphorus per Cent.	Yield Point, Tons per Square Inch.	Ultimate Stress, Tons per Square Inch.	Elongation in 6 Inches per Cent.	Reduction of Area per Cent.
1	0·040	20·4	33·1	23·00	52·0
2	0·300	25·4	39·9	23·00	45·3
3	0·500	32·00	44·2	20·00	45·3

Alternation Stresses by the Wöhler Method.

Tensile stress	15 tons.
Range of stress	30 ,,
Revolutions per minute . .	1200

No.	Phosphorus per Cent.	Revolutions to Fracture.	Ratio.
1	0·04	61,085	1·0
2	0·30	167,690	2·74
3	0·50	651,490	10·65

Impact Tests by Mr. Frémont.

The tests were made on saw-cut notched bars, 10 millimetres by 8 millimetres section.

No. 1, with 0·04 per cent. phosphorus, broke with an expense of work = 8 kilog.
,, 2 ,, 0·30 ,, ,, ,, ,, = 1 ,,
,, 3 ,, 0·50 ,, ,, ,, ,, = 1 ,,

The tenacities calculated from the results were respectively as follows, namely—

No. 1, with 0·04 per cent. phosphorus	50 kilog. per mm.^{2}
,, 2 ,, 0·30 ,, ,, ...	62 ,, ,,
,, 3 ,, 0·50 ,, ,, ...	85 ,, ,,

These results were remarkably similar to those obtained in the Buckton machine, with the exception of the third, which was lower. Mr. Frémont remarked that these steels were all brittle. Even No. 1 should have been more resistant, whilst in Nos. 2 and 3 the brittleness was normal for steels of corresponding tenacity, for they could not bear the notch. "They may, however, not be of superior quality."

Alternating-strain Tests by Professor Arnold.

The mean results of duplicate tests were as follows, namely, the bars were $\frac{3}{8}$ inch square. Alternations 660 per minute. Deflection of the test-piece 3 inches above the die-face was $\frac{3}{8}$ inch on each side.

No.	Phosphorus per Cent.	Reversals to Fracture.	Ratio.
1	0·04	271	100
2	0·30	200	73
3	0·50	100	37

Professor Arnold remarked that No. 1 was only of moderately good capacity to resist alternating stresses. No. 2 was unsuitable for bolts and alternating parts of high-speed engines, whilst No. 3 was rotten.

Slow Alternating-bend Tests.

The tests were made in Middlesbrough by bending strips $\frac{3}{8}$ inch by $\frac{3}{16}$ inch by 3 inches backwards and forwards, through an angle of 30° until they broke.

No.	Phosphorus per Cent.	Reversals to Fracture.	Ratio.
1	0·04	605	100
2	0·30	446	73
3	0·50	150	24

The tensile, slow bending, and Wöhler tests were made in Middlesbrough. The shock tests were made in Paris by Mr. Frémont, and the alternating-strain tests by Dr. Arnold at Sheffield.

These results are most interesting, and show that phosphorus, under certain conditions, is not such a *bête noir* as it is painted. It must be noted, however, that the bars tested had been forged down from 6-inch cubes, and the tests were all made in a longitudinal direction. When the same steels were rolled into sheets or plates, although they stood well if bent across the direction of extension, they failed if bent at right angles to that direction. Phosphorus in steel, however, for certain purposes is valuable, and a considerable quantity of steel containing between 0·1 and 0·15 per cent. phosphorus is used to-day in small sections, and for purposes in which the stresses are generally applied at right angles to the direction of rolling.

A valuable paper published in August 1914 in *Ferrum* by E. d'Amico ([58]), on the influence of phosphorus on the mechanical properties of mild steel, gives important results which are here summarised.

The basis was a steel containing—

	Per Cent.
Carbon	0·118
Manganese	0·400
Silicon	0·247
Sulphur	0·051
Phosphorus	0·012

The mechanical properties were as follows:—

	Tons per Sq. Inch.
Elastic limit	13·3
Tensile strength	26·8
Elongation	28·0
Contraction of area	61·5

The addition of each 0·10 per cent. phosphorus up to 0·41 per cent. affected the quality to the degree shown in the following statement:—

1. The elastic limit is raised 2·32 tons.
2. The tenacity limit is raised 4·1 tons.
3. The elongation is reduced 1·36 per cent.
4. The contraction of area is reduced 3·81 per cent.
5. The specific gravity is reduced 0·018 per cent.

6. The resilience, as shown by Charpy's shock test, decreases continuously with increase of phosphorus, and when it exceeds 0·25 per cent. is practically nil.
7. The electrical resistance is increased proportionately with increase of phosphorus at the rate of 0·11 ohms per 0·1 per cent. (referred to a wire 1 m.^{2} and 1 metre in length).
8. The permeability is increased while the coercive force remained, and hysteresis losses are decreased by the addition of phosphorus.
9. The Brinell hardness number is increased 12 points per 0·1 per cent. phosphorus.

SECTION II.

In this section is recorded the more recent research on many of the subjects referred to in Section I.

The following matters will be discussed:—

1st. Further studies of blast-furnace "bears."

2nd. The formation of a phosphide of iron-iron constituent having pearlitic characteristics.

3rd. Discussion as to the conditions favourable for the separation of idiomorphic crystals from solid solutions of phosphorus and iron.

4th. The unequal distribution of phosphorus in the metals taken during the "after-blow" in a basic-lined Bessemer converter.

5th. The heterogeneous character of wrought irons.

6th. The distribution of phosphorus in steel, in ingots poor and rich in phosphorus, in steel rails, &c.

7th. On the synthetic production of ghost lines, and the influence of ghost lines on the strength of steel.

8th. The result of experiments on a soft steel plate proving that the parts rich in phosphorus constitute the white ghost lines, and that they are last to be invaded by carbon on heating up and the first to part with carbon on cooling.

9th. Experimental evidence showing that the parts of iron or steel bars which contain phosphorus concentrations resist carburisation by cementation.

10th. How it is that phosphorus in steel tends to cause the crystals in castings to be small, and that the purest castings contain the largest crystals.

1. *Further Studies of Blast-furnace Bears.*

Soon after the discovery of the dephosphorised Skinningrove bear, a bear with a similar columnar structure was found in the hearth of a Cleveland furnace of Messrs. Bolckow, Vaughan & Co., Ltd., Eston. The columns, all of them vertical, were between ⅛ and ¼ inch in diameter, and were so loosely attached that in some parts they could be separated by hand. The columns of this bear contained considerably less phosphorus than Cleveland iron, but no specimen contained as little as some of the columns of the Skinningrove bear.

In 1900 I described a remarkable piece of metal found in the hearth of one of the furnaces at Ferryhill. This consisted of columnar crystals of iron free from carbon but fully saturated with phosphorus in solid solution. The walls of the columns consisted of iron phosphide. The source of this specimen must have been liquid pig iron containing at least 3 per cent. carbon and 2 per cent. phosphorus and about the same amount of silicon. Exactly how the silicon and carbon were eliminated could not be determined, but there can be no doubt that this was effected by oxidation.

The very wonderful bear found in and below the hearth of one of the Skinningrove furnaces I have already referred to on p. 143.

Specimens of bears from other furnace hearths have been handed to me by Cleveland pig-iron makers.

A most interesting specimen was supplied by Mr. A. O. Cochrane from a bear in an Ormesby furnace which had been in blast for thirty-eight years. In this example diffusion had occurred without the elimination of carbon and silicon.

	Per Cent.
Manganese	0·417
Total carbon	3·944
Combined carbon	traces to 0·7
Silicon	2·034
Sulphur	0·041
Phosphorus	0·437

As will be seen from this analysis, the phosphorus, as in the Skinningrove bear, is considerably lower than in Cleveland iron, and it is evident that in thirty-eight years about two-thirds of the original phosphorus had been removed. There was no indication of columnar structure such as was found in the Skinningrove bear, but I have little doubt that pressure was the cause of elimination.

Originally the iron mass weighing more than 100 tons would contain the whole of the carbon in the combined state, and in cooling slowly the iron carbide would separate into iron and graphite before the ternary iron-carbon-phosphorus eutectic had solidified. This decomposition would be accompanied by considerable expansion—probably more than 5 per cent. in volume. The expanding metal, not being able to burst or move the walls of the hearth outwards, would produce great internal pressure, and this, in my opinion, would be sufficient to squeeze out a large part of the phosphorus eutectic, which would naturally flow upwards towards the hottest part just below the hearth level. The main point of interest, however, is that the phosphorus which remained in the metal was completely and homogeneously diffused in solid solution, and the whole of the carbon existed as graphite. Photograph No. 9 (Plate XXVI.) represents this.

A second sample supplied by Mr. A. O. Cochrane from the bear, weighing several hundred tons, of a furnace which had been in blast for six years, had the following analysis:—

	Per Cent.
Combined carbon	0·38
Graphite	3·07
Manganese	0·10
Silicon	1·13
Sulphur	0·15
Phosphorus	0·63

The central portion of the bear was more readily fractured vertically than in any other direction, and an examination of the fractured surfaces showed indications that one part had been sliding against the other, but the sliding planes were not so continuous as those found in the Skinningrove bear. The evidence, however, was sufficient to show that it had been subjected to circumferential pressure. The joints of the parts that had been extended contained some oxide of iron and the whole mass was somewhat porous. This peculiarity is explained by the fact that the central part of the bear was the last part to cool down, and in contracting split up along the planes of slip, and the porosities so produced admitted air and water, which, during exposure for many years after the furnace had ceased to work, were certain to penetrate the mass and oxidise the faces of the slip-planes.

The phosphorus remaining existed partly in the eutectic areas, and was partly diffused in the metallic matrix which was very coarsely pearlitic—indeed, etched specimens resembled precious opal.

The microstructure exhibited some features of unusual interest. The heat-tinted structure has been reproduced in colour and is shown in photograph No. 2 (Plate XXII.).

The previous researches on the ternary alloys of iron, carbon, and phosphorus enable me to explain exactly what occurred during the cooling down from 945° C., the solidifying point of the iron-carbon-phosphorus eutectic. The ground mass or metallic part would consist of solid austenite and solid iron-carbon-phosphorus eutectic. From the latter the carbide would diffuse and a portion decompose into graphite and iron, but coincidently the phosphide would also diffuse and the diffusion be arrested by falling temperature—above 700° C. and under 945° C. At this point the matrix would contain phosphorus, silicon, and carbon in solid solution and free F_3C.

As the temperature continued to fall, the austenite would decompose and free carbide appear in laminæ with the formation of pearlite.

When excess carbide of iron is in solid solution the excess over the eutectoid proportion is attracted by any solid body, and falls out of that solution on cooling, at the solid surfaces, whether they be slag, carbide of iron, or free phosphide of iron. It will be noticed in the photograph that the phosphide areas coloured blue are sheathed by carbide, coloured red, and that between this carbide layer and the termination of the pearlite plates there is a carbonless area. The terminations of the carbide plates are thickened, a proof that it had commenced to globularise. On reheating to about 900° C. and cooling in air the carbide envelope no longer sheathed the phosphide, but was distributed in the matrix. The reheating to 900° C.

had caused the carbon to diffuse and return to the condition it was when at the same temperature in cooling down. Had the cooling been slow enough after reheating there can be no doubt that the carbide would again have crystallised round the phosphide, but being rapid it separated in meshes in the matrix.

2. *The Formation of a Phosphide of Iron—Iron Constituent having Pearlite Characteristics.*

In my first paper on iron and phosphorus I described a remarkable case in which an alloy containing about 2 per cent. phosphorus and 0·12 per cent. carbon was carburised by Messrs. Thomas Sorby & Sons, in one of their cementation furnaces. It was shown that as the carbon passed into the metal it precipitated the phosphide of iron from solid solution, and this, combining with a portion of the carbide, became liquid and liquated out of the alloy, leaving radial columns of carburised metal which nearly reached the centre of the piece, and a kernel in the middle free from carbon, surrounded by a most beautiful pearlitic fringe. That specimen is one of the most interesting alloys I have ever examined, and has been the object of much investigation. On examining the polished surface after heat-tinting, it was found that the pearlitic fringe was not of the same constitution as ordinary pearlite, for, instead of the hard constituent being entirely carbide, the greater portion was phosphide, and what carbide there was had more or less segregated between the plates of phosphide. The colour photograph No. 10 (Plate XXVII.) most clearly illustrates this. We have here a case in which phosphide of iron and iron and carbide of iron have formed a ternary eutectoid having exactly the same appearance as ordinary pearlite, indeed I mistook it for that substance and described it as such, in my original paper—an object lesson that "things are not always what they seem."

I have endeavoured to explain how it was formed in a paper read elsewhere (42), to which those interested are referred.

3. *Discussion as to the Conditions favourable for the Separation of Idiomorphic Crystals from Solid Solutions of Phosphorus and Iron.*

It is well known that free phosphide does crystallise from solid solutions even when very little phosphorus is present.

The meteoric iron from Bolsom de Mapimi, Cohahuila, Mexico, and many others contain almost perfectly formed idiomorphic crystals of the metaral called rhabdite, a double phosphide of iron and nickel.

The analysis, made in my laboratory, of this meteorite is as follows:—

	Per Cent.
Iron	94·009
Nickel	5·050
Cobalt	0·599
Sulphur	0·027
Phosphorus as free phosphide	0·210
,, in solid solution	0·067
Manganese, copper, arsenic, chromium, and tungsten	nil
	99·962

On melting and subsequently slowly cooling this meteorite, all the phosphide was found in solid solution, and annealing did not cause it to separate. Obviously there must be a range of temperature in which the phosphide crystallises out of the solid iron, but what that is has not yet been discovered. It is probable that only by maintaining the metal in that range for very long periods can separation be effected. This field is open to younger men who have the prospect of a long life before them during which the prolonged trials can be made.

It is certain that no idiomorphic crystals of phosphide have ever been found in terrestrial iron containing only 0·27 per cent. of phosphorus. I have not given up hope that some time they may be. That free phosphide does separate in crystals from alloys very rich in phosphorus was shown in 1900.

A portion of the metal, containing 2 per cent. phosphorus and 0·12 per cent. carbon, referred to on p. 159, was twice submitted to the malleablising process, with the object of removing the carbon and to cause as much phosphorus as possible in the eutectic to diffuse into the iron after the removal of the carbon. To my astonishment, although the first object was attained and all the carbon was removed, yet instead of having less free phosphide, the quantity had increased. In other words, under the treatment some of the phosphide had crystallised out of solid solution, and instead of being in a eutectic, as it originally existed, it now appeared in plates arranged along the cleavages of the iron crystals. The crystals were completely insoluble in dilute acids; they were separated and tested, and found to consist of perfectly pure Fe_3P. Their sides were highly crystalline, from which it would appear that during their crystallisation from the solid solution they were disposed to take idiomorphic form, but were prevented from completely doing so by the rigidity of their environment. Photograph 11, Plate XXVI., represents the side of one of these plates.

4. *The Unequal Distribution of Phosphorus in the Metals taken during the "After-blow" in a Basic-lined Converter.*

Owing to the kindness of Dr. Arthur Cooper, his metallurgist, Mr. C. H. Ridsdale, took for me a series of samples during an "after-blow" at the North-Eastern Steel Works. The analyses were as follows:—

	Carbon per Cent.	Manganese per Cent.	Phosphorus per Cent.
1st sample	0·025	0·305	1·2
2nd ,, ...	0·050	0·466	0·95
3rd ,, ...	0·050	0·562	0·52
4th ,, ...	0·050	0·530	0·28
5th ,, ...	0·035	0·318	0·09
6th ,, ...	0·025	0·120	0·03

Brinell Hardness, before and after annealing in 3 tons of Molten Blast-furnace Slag.

	Before Annealing.	After Annealing.	Phosphorus per Cent.
No. 1	228	...	1·20
,, 2	217	150	0·95
,, 3	179	156	0·52
,, 4	149	131	0·28
,, 5	126	107	0·09
,, 6	103	86	0·03

It is possible that the softening produced by annealing may be due to the more equal distribution of the phosphorus and the complete segregation of the carbon in the form of filaments of Fe_3C, or that incipient separation of free phosphide had been effected.

They were all polished and etched, and a selection of the specimens were photographed and are reproduced in photos Nos. 12 and 16.

It will be seen that in every case certain parts are dark while others are white. The darker parts represent the portions that first fell out of solution, and are those containing the lesser proportion of phosphorus. In the sample containing only 0·03 per cent. (No. 16) the contrasts between the rich and less rich portions are feeble, but nevertheless are quite distinct.

This marked variation in the phosphorus explains how it is that, after forging and breaking the test-pieces containing between 0·08 to 0·2 per cent. phosphorus, the fractures are composite, with fine and coarse crystals present in the same pieces. The coarse crystalline portions are those highest in phosphorus, and their presence is explained by the property phosphorus confers on iron, of preventing or retarding recrystallisation after forging.

When in a test ingot there are large crystals, some of which contain phosphorus in appreciable proportions and other crystals of purer iron, although forging shatters both of them, the first do not readily recrystallise, while the latter do. It is the presence of parts not recrystallised in the fractured test-pieces which indicates to the Bessemer blower that the phosphorus is not sufficiently eliminated and that further blowing is necessary. It is these parts in the test-pieces, which do not recrystallise after forging, that strongly resist the attack of the new reagent.

The remarkable structure shown in photograph No. 14, Plate XXVIII., of one of the after-blow metals is difficult to explain. It is possible that the minute quantity of carbon is responsible for the peculiar form of the primary crystallites. It has been observed in many specimens containing between 0·08 and 0·50 per cent. phosphorus and about 0·05 per cent. carbon.

5. *The Heterogeneous Character of Wrought Irons.*

The photographs Nos. 17 to 21 (Plates XXIX. and XXX.) show that all wrought irons are more or less heterogeneous. The more homogeneous and the purer they are, the less pronounced are the contrasts, and the sooner are the portions higher in phosphorus attacked and copper from the reagent deposited on them. In the cases illustrated the irons have been attacked for one minute, and then have had five successive applications of one drop on the surfaces for one minute. These are shown side by side for comparison. The attack by the reagent results in the progressive deposit of copper inversely to the concentration of phosphorus.

It should be observed that after two applications the Swedish irons become completely covered with copper, while the best Yorkshire irons still contain white parts unattacked after five consecutive applications of one minute's duration. Cleveland wrought iron, even after ten successive attacks, still retained bright portions. The analyses of these irons were as follows:—

		Phosphorus.
No. 21.	Swedish iron	0·008 per cent.
,, 17.	Best Yorkshire	0·123 ,,
,, 18.	,, ,, ...	0·073 ,,
,, 19.	,, ,, ...	0·121 ,,
,, 20.	Cleveland iron	0·310 ,,

It is possible that the white portions shown in the Yorkshire irons contained 0·2 per cent. to 0·3 per cent. phosphorus, and in the Cleveland bar, No. 20, after ten attacks, 0·8 per cent. It seems certain from these results that the method of etching applied, in the manner described, to the examination of wrought iron is capable of showing whether or not the "piles" used in their manufacture are mixtures of good and inferior iron, or of good and homogeneous material.

6. *The Distribution of Phosphorus in Steel Ingots, Poor and Rich in Phosphorus, and in Steel Rails, &c.*

Although the phosphorus is almost perfectly distributed in blown Bessemer metals containing practically no carbon and 0·03 per cent. phosphorus, it is not so when appreciable amounts of carbon are present. It may be accepted as an established law, that as the carbon is increased in fluid metal, the phosphorus becomes more and more concentrated in the portions last to solidify.

For instance, the phosphorus in very grey hæmatite iron is concentrated in independent nuclei, in the form of a eutectic containing from 7 to 10 per cent., while in the purest steels containing from 0·4 per cent. to 1·5 per cent. carbon, it is found in concentrated solid solution in and about the crystals, and never in the free state.

Photographs No. 23 (*a-b-c-d*), Plate XXXI., represent cast phosphorettic steel having the following analysis:—

	Per Cent.
Carbon	0·17
Silicon	0·187
Phosphorus	0·390

Photograph No. 23 (*a*) represents a section after etching, magnified only 5 diameters. The fir-tree primary crystallites (dark) are most clearly shown and contain very little phosphorus, for the copper of the etching reagent has deposited on them, while the white portions between are very rich in that element.

Photograph (*c*) is a larger magnification of part of the same, while photograph (*d*) is the same area as the last after ten successive applications of the etching fluid, in which only the parts most highly enriched in phosphorus remain unattacked. They were the very last parts to solidify.

Photograph (*b*) is a part of the same material etched by acidulated alcohol, a reagent which darkens the parts where the carbon is concentrated. This illustrates a most important law, that although the primary crystallites at the time of their formation contain little or no carbon (that element being associated in concentration with the phosphorus in the last portions to solidify), during cooling the carbon diffuses back into the purer crystallites and is concentrated in their central axes, a process that is reversed on gradually remelting.

Ingots made by the basic open-hearth process for the manufacture of modern steel rails contain between 0·02 per cent. and 0·03 per cent. phosphorus and about 0·6 per cent. carbon.

A section cut from one of these ingots about 3 inches from the outside is illustrated by photographs No. 22 (*a*, *b*), Plate XXX. The first was etched by an acid fluid, the second by the cupric reagent. In the acid etched steel structure no trace of the primary crystallites appear, but in the other the purer primary crystallites surrounded by metal that solidified after the formation of the primaries are clearly in evidence. After repeated attacks the white areas gradually became less and less marked, till finally only minute white portions remained where the phosphorus was most highly concentrated.

As one would naturally anticipate when steel ingots are rolled into bars or rails, the parts rich in phosphorus are extended into threads or plates, and can be readily detected in longitudinal sections. An example of this was shown many years ago in my paper on "Crystallisation and Segregation in Ingots," and is reproduced in photograph No. 24, and a second example from a rail containing 0·03 per cent. phosphorus is shown in photograph No. 25.

Photograph No. 26 (*a*, *b*, *c*) is from a crucible steel ingot containing carbon, 0·45 per cent.; phosphorus, 0·012 per cent.; and photograph No. 27 is part of charge No. 2, to which 0·08 per cent. phosphorus was added (Plates XXXII. and XXXIII.).

Photographs No. 28 (*a*, *b*, *c*), Plate XXXIV., represent a steel ingot containing 1·20 per cent. carbon and 0·012 per cent. phosphorus etched in the same way as the last. The phosphorus is most concentrated in the form of globular inclusions representing the very last parts to completely solidify. In these photographs the free cementite is also white, but as the lines always remain clearly defined, and do not alter after repeated attack, it is easy to see they are not portions rich in phosphorus.

Photograph No. 8, Plate XXV. (*a*, *b*, *c*, *d*).—Cast steel test-piece referred to on p. 150.

7. *On the Synthetic Production of Ghost Lines, and the Influence of Ghost Lines on the Strength of Steel.*

In order the better to study the peculiarities of ghost lines, a sheet of soft iron was cut into strips, and between them powdered iron-phosphorus-carbon eutectic was placed. The pile so produced was heated to 1000° C., a temperature which caused the powder to melt. It was then forged down to a ½-inch sheet. The excess eutectic was squeezed out from between the layers, leaving the juxtaposed faces perfectly united with a thin layer rich in phosphorus. After very slow cooling sections were cut, polished, and etched. The structure was identical with that so often found in ship and boiler plates, consisting of strings of disconnected patches of pearlite and straight lines of ferrite. The white lines, representing the junction of the original plates of carbonless iron, were quite free from carbon. The phosphorus had diffused to a slight extent into the iron, and the whole of the carbon originally associated with the phosphorus was found in the iron beyond the phosphorettic junctions.

The average phosphorus in the plate was about 0·2 per cent. and the carbon about 0·12 per cent. Typical ghost lines had thus been produced synthetically. The plate was then heated to about 1350° C., and was very slowly cooled to 700° C. during a period of about three days. On examination of the plate when cold, both the phosphorus and carbon were found to be perfectly and evenly distributed, and no evidence of ghost lines could be detected.

By subjecting a bar of steel, containing about 0·3 per cent. of phosphorus and an equal amount of carbon, to the same drastic heat treatment, a similar change was effected ([35]). Before annealing, the bar consisted of ghost lines and lines of pearlite, the former being rich in phosphorus and free from carbon. After the treatment not even the most delicate methods were able to detect any variation in the phosphorus, and the carbon was distributed more equally. The diffusion of phosphorus being complete, although there were slag inclusions drawn out into threads, they were not enveloped by ferrite, and ferrite ghost lines were absent.

When it is recalled that large forgings are sometimes rejected on account of white ghost lines or phantom streaks only detectable after rough turning, and that some forgings which served their purpose satisfactorily have contained many of the same lines, one is forced to question whether there is sufficient evidence that ghost lines are as harmful as some people imagine.

After careful study I am inclined to believe that if they are not associated with a material amount of slag inclusions, they are not dangerous or liable to lead to the failure of engineering structures. I am led to that conclusion by submitting cross sections to violent shock-test so that the stress applied is greatest across the lines, for when this is done fracture does not start where they are located unless there are sulphide or slag inclusions in material quantity. The subject should have more consideration and be thoroughly investigated by making suitable mechanical tests.

The term "ghost" and "phantom" indicates an important fact, namely, that the lines are not deep seated; they are completely removed by turning off a thin layer of the steel, and apparently reappear in other places, which of course means that they are irregularly distributed, very attenuated, and that those below the surface are made visible when the layer covering them is removed.

It seems certain that the hotter the steel is poured, the larger the mass, and the consequent greater period during which the steel crystallises, the more liability is there for the formation of local intercrystalline segregations, which on being extended by forging become ghost lines. The portions which are rapidly chilled by contact with the mould sides, if free from honeycombs, are always the parts free from local segregations. Steel cast in sand moulds, or metal moulds lined with sand, are not chilled to any material extent, and the outer walls are not so homogeneous as the corresponding parts of steel ingots cast in iron moulds.

The appearance of white ghost lines in forgings is largely the result of the heat treatment to which the metal is subjected. If after heating, which causes perfect distribution of the carbon, the metal be oil cooled, the time of cooling is not sufficiently rapid to admit of the expulsion of the carbon from the more phosphorised areas, and if the chilled forgings be reheated to temperatures below the critical point A_1, the steel will be softened, but the carbon will not diffuse out of these areas.

The three photographs No. 32 (Plate XXXVII.) are taken from a test-piece cut from a large forging: (*a*) in the state as received, (*b*) after heating to 900° C. and cooling in air where it passed from 900° C. to 600° C. in twenty minutes, and (*c*) is the same area as (*b*) etched by the cupric reagent.

(*a*) shows ghost lines.

(*b*) is free from any trace of these lines.

(*c*) shows that although no ferrite lines are visible or present the phosphorus lines are present, and, as was proved by very slow cooling of this specimen, the phosphorus expelled the carbon with the reappearance of broad ferrite bands.

8. *The Result of Experiments on a Soft Steel Plate, proving that the Parts rich in Phosphorus constitute the White Ghost Lines, and that they are last to be invaded by Carbon on heating up, and first to part with Carbon on cooling.*

In order to determine whether the ghost lines in a steel plate could be removed and restored by heat treatment, a plate having the following analysis was selected:—

	Per Cent.
Carbon	0·135
Manganese	0·37
Silicon	traces
Sulphur	0·067
Phosphorus	0·061
Copper	0·061

Phosphorus was clearly proved, by the aid of the new reagent, to be present in the white lines, and these were associated with sulphide inclusions. The plate was heated to about 1200° C. and was cooled down to atmospheric temperatures in about four days.

The structure of the metal after this treatment was entirely changed. The pearlite, instead of being in minute, detached particles longitudinally arranged in lines relatively close together, occurred in lines wide apart and separated by parallel broad bands of ferrite. Instead of being in the form of minute detached islands, the pearlite existed in almost continuous bands, broken at relatively wide intervals.

This specimen was an ideal one on which to work and prove, first, the effect of heating at different temperatures in causing the carbon to diffuse into the phosphorised ferrite layers, and, secondly, to determine whether, after the carbon became perfectly diffused, on cooling, it would return to its original position.

Several portions were cut from the plate, and these were heated in duplicate to 750°, 780°, 820°, 850°, 900°, 930°, and 1000° C. respectively. One of each of the pieces was quenched in water, the other being allowed to cool in air.

The specimen quenched from 750° C. could not be filed or sawn, while that quenched from 1000° C. was relatively soft.

This apparent anomaly was soon explained after an examination under the microscope, for the specimen quenched at the lower temperature consisted of relatively thick bands or layers ? of hardenite embedded in soft ferrite. These bands were so securely anchored in the metal that the saw and file simply skidded over their surfaces. The same plate, before the drastic annealing, heated to and quenched from the same temperature or 750° C. was easily filed and sawn. In each the pearlite had been changed to hardenite, and the hardenite was in the same proportion as the pearlite.

The former resembled a field containing ridges and boulders of outcropping granite, the latter the same field with the granite broken up into a large number of small detached pieces and distributed through the soil. A ploughman could not make furrows in the first, but could readily plough the second, and for the same reason the file and saw could not cut the hardened steel with ridges of hardenite, but were capable of readily cutting the steel containing the hardenite in subdivided particles, and still more readily could the steels which had been heated and quenched from 1000° C. be cut, for hardened in this way the steel had only the average hardness of thoroughly intermixed hardenite and ferrite.

Four pieces of the plate were heated at 1000° to 1100° C. and cooled at different rates. One piece, taken directly from the muffle and cooled in air in less than one minute, was proved on etching to have a most homogeneous structure and no trace of any ghost lines was visible. This is illustrated by photo No. 29 (*k*), Plate XXXV. The second, third, fourth, and fifth were cooled progressively more slowly, (*m*) in ten minutes, (*n*) in half an hour, and (*o*) in one hour. All the specimens, when at 1000° C., had the carbon uniformly distributed, but when time was afforded in the cooling process, the carbon diffused into longitudinal seams leaving bands or micro-ghost lines of carbonless ferrite. On applying the new reagent to specimen (*k*) the phosphorus bands remained bright together with the pearlite patches, while all the other parts of ferrite, shown dark in the photograph, became coated with copper.

The microstructure of the plate, before and after annealing and heat treatment, is shown in series No. 29 (*a*) to (*o*).

(*a*) represents the acid etched plate before annealing, in which both the ghost lines and other ferrite remain white and the pearlite dark.

(*b*) represents the same steel etched by the new reagent which has left the ghost lines and the phospho-ferrite white and the purer ferrite dark.

(*c*) is the same plate after annealing by heating to about 1200° and slowly cooling from that temperature.

(*d*) is a portion of the plate heated to, and quenched from, 750° C.; the white bands represent hardenite embedded in ferrite.

(*e*) Heated to and cooled from 780°, etched by acid.
(*f*) ,, ,, ,, ,, 800° ,, ,,
(*g*) ,, ,, ,, ,, 850° ,, ,,
(*h*) ,, ,, ,, ,, 880° ,, ,,
(*i*) ,, quenched from 900° ,, ,,
(*j*) ,, ,, ,, ,, 920° ,, ,,
(*k*) ,, ,, cooled from 1000° ,, ,,
(*l*) ,, ,, ,, ,, 1000°, etched with the new reagent.

(*m*) Heated to and slowly cooled from 1000°, etched by acid.

(*n*) Heated to, more slowly cooled from 1000°, etched by acid.

(*o*) Heated to, more slowly cooled from 1000°, etched by acid.

It will be seen, in photo (*l*), that the phosphorised portions in the plate drastically annealed at high temperatures are much wider than they were in the original plate and are shaded at their boundaries.

The explanation is not difficult, for the high temperature to which the steel had been subjected caused the phosphorus to diffuse laterally and merge with the other bands rich in phosphorus, forming wider bands more dilute in that element than those in the original plate; on slow cooling the carbon diffused out of these and passed into the purer parts where there is least phosphorus. Had the cooling, after reheating to 1000° C., been much slower, there can be no doubt the pearlite would have segregated into the same lines, shown in (*e*).

The results speak for themselves, and not only show that phosphorus in ferrite resists the entrance of carbon into it on heating up, but rejects it on slow cooling.

9. *Experimental Evidence showing that the Parts of Iron or Steel Bars which contain Phosphorus Concentrations resist Carburisation by Cementation.*

As has been stated, carbon at an early period during the cooling of low-carbon steels diffuses out of the phosphoretted portions, and is slow to return on reheating, and it seemed probable that if present in iron it would resist carburisation by cementation. That it does so was proved by the carburisation of phosphorettic wrought iron by blast-furnace gas at a temperature under 600° C., for while the purer portions were almost completely converted into carbide of iron (Fe_3C), very little carbide was formed in the portions rich in phosphorus. The experiment was repeated, with the same result, by subjecting to the same process a bar consisting of layers of pure iron sandwiched between layers of iron rich in phosphorus. A further trial, confirming previous observations, was made in which the face of a section, cut from the centre of a bar of segregated steel, was carburised. The purer steel on each side of the segregated part rich in phosphorus became highly carburised, whilst the segregate itself was scarcely affected.

Phosphorettic iron (0·40 per cent. phosphorus), although incapable of being recrystallised on heating alone, breaks up into small crystals when carbon is caused to diffuse into it, a seeming proof that whilst phosphorus prevents the change of α- to γ-iron, carbon restores the possibility.

Large crystals of iron during interdiffusion with carbon in soft and medium soft steels in the range called the α-β coincidentally break up into small ones, which appears to indicate that as the iron is invaded by the carbon it is changed to γ-iron, and that this change may occur gradually with rising temperature with the coincident absorption of heat over the whole range—a hypothesis emanating from Osmond. Grenet suggests that the heat absorbed during this change is due to the solution of the carbon in the iron, but neither Grenet nor any one else has explained the significance of the recrystallisation.

10. *How it is that Phosphorus in Steel tends to cause the Crystals in Castings to be Small, and that the Purest Castings contain the Largest Crystals.*

When there are parts richer in phosphorus than others in carbon-steel castings, and the steel is reheated to refine the structure, the parts richest in phosphorus will usually have the smallest crystals.

The lower the phosphorus the larger will be the crystals in steel castings, the reason being that the primary crystallites, during development in the more phosphorised steel, are purer than the remaining liquid which precedes them in the mould. This concentration lowers the freezing point and admits the growth of new crystallites beyond the impure liquid, and these also get surrounded by a liquid of lower freezing point than that of the primary crystallites beyond them, and the process is repeated till the whole mass is solid. On the other hand, when phosphorus is absent or very low, the primaries continue to grow unchecked for a longer distance and larger crystals result. This peculiarity occurs only in steels containing a sensible proportion of carbon. If the carbon is much below 0·3 per cent., phosphorus leads to the development of large columnar crystals.

SECTION III.

New Method for Detecting Variations of Phosphorus in Iron and Steel.

Many years ago I noticed that very dilute aqueous solutions of copper chloride deposited copper unevenly on polished surfaces of steel; some portions remained bright, while on others copper was deposited and appeared red. On experimenting on steels with ghost lines, in which it had been proved by the "heat-tinting" process the phosphorus was in segregation, the action was most erratic; sometimes the copper deposited on the purer portion, and at other times it deposited on the parts rich in phosphorus. Some time ago, when Dr. Rosenhain asked me if I had used copper solutions to etch steel, I replied in the above terms, but subsequently reinvestigated the action of copper salts on steel. I substituted alcohol for water, omitting the ferric chloride, the presence of which is considered necessary by Dr. Rosenhain and Mr. Haughton ([43]), and instead of immersing the specimen in the reagent as is their practice, I simply cover the specimen with the exceedingly dilute alcoholic cupric solution. I then found that the copper invariably first deposited on the purer portions freest from phosphorus, and so sensitive was the selective action of the reagent that differences of less than 0·01 per cent. phosphorus, and irregular distribution of phosphorus in all wrought irons and steels could be detected. The composition of this reagent is given below.

The reagent is made by mixing—

Cupric chloride . . .	10	grammes.
Magnesium chloride . .	40	,,
Hydrochloric acid . .	20	cubic centimetres.
Alcohol to make up to .	1000	,, ,,

The salts are dissolved in the least possible quantity of hot water and the solution made up to 1000 cubic centimetres with alcohol. Magnesium chloride is not necessary, but better results are, if anything, obtained by having it present.

The specimens are simply covered with a thin layer of the reagent and must on no account be immersed in a bath of the liquid. The layer of liquid, after remaining on the surface for one minute, is shaken off and a second layer dropped on the surface and left there for the same period. This procedure is repeated as often as it is found desirable. The specimen is washed with boiling water, then with methylated spirits, and shaken to remove the spirit from the surface, the heat imparted by the boiling water rapidly evaporating the last traces of alcohol. The copper is usually left as a hard coherent layer, and is not readily removed by rubbing; indeed, the specimens may sometimes be repolished by rouged chamois leather without disturbing the deposited copper. The reagent not only indicates variations of phosphorus, but by progressive etching one can get a very good idea as to the degree of difference between the phosphorus in different portions of the same metal. If the reagent be applied in successive portions and the difference in the proportion of phosphorus be slight, as stated above, the copper invariably precipitates on the purer portion first; but on repeated application the copper gradually deposits also on the parts richer in phosphorus, and after many applications of the reagent the whole surface, including the phosphorised parts, becomes coated with copper. If, however, the phosphorus be very much concentrated in one or more parts, these remain perfectly bright and free from copper even after ten applications of the reagent.

In order to show the relative sensitiveness of the new method as compared with the old "heat-tinting" process, a piece of pure Armco iron, manufactured by the Shelton Iron, Steel & Coal Company, Limited, was phosphorised in one single spot by making a small hole in it and filling it with iron phosphide, after which the bar was heated to whiteness to enable the phosphorus to melt and diffuse into the surrounding iron. After cooling, the surface of the bar was ground down to below the point where the original drill hole had penetrated so as to admit the examination of the iron below, into which the phosphide had diffused. The surface after polishing was first etched so as to develop the crystalline structure of the iron; it was then heated until the phosphorised part was brown and the surrounding iron pale yellow.

It was then photographed. The section was repolished and treated with one application of the new reagent, after which it was again photographed. The photographs of the same area, after developing in the manner described, are placed side by side and are reproduced in No. 31 (*a*) and (*b*), Plate XXXVI. It will be observed that one application of the new reagent left the whole of the phosphorised parts perfectly free from any copper deposit, and also that the phosphorus in diffusing preferentially travels between the junctions of the crystal grains. These branches or ramifications diminish in phosphorus as they extend outwards, as was proved by the continued application of the reagent, for the copper began to be deposited on their terminations, and eventually they were completely covered, leaving only a round white disc. On continuing the attack the white disc became smaller and smaller, until eventually only a small spot in the centre remained free from deposited copper. This gradual deposition of the copper commencing at the extremities and extending towards the centre indicates that the phosphorus was in greatest concentration at the centre and the least at the ends of the branches.

Heat-tinting was not sufficiently sensitive to detect the very dilute solid solution of the phosphorus in the intergranular ramifications, but was capable of indicating that the centre of the disc contained more phosphorus than the outer part.

It is probable that the reagent described by Rosenhain and Haughton (43), which is as follows:—

Ferric chloride (Fe_2Cl_6)	30 grammes
Hydrochloric acid (conc.)	100 cubic centimetres
Cupric chloride ($CuCl_2$)	10 grammes
Stannous chloride ($SnCl_2$)	0·5 ,,
Water	1 litre

may give identical results, but in my own experience it is not so certain in its action as the one above described.

Mr. J. H. Whiteley, in a paper read before the Cleveland Institution of Engineers (53), described a method for detecting the parts richest in phosphorus in steel castings. According to Mr. Whiteley, his reagent is made by dissolving 0·04 gramme copper oxide (CuO) in 6 cubic centimetres of strong nitric acid (HNO_3), and making up to 200 cubic centimetres with methylated spirits. In working with this reagent Mr. Whiteley prefers to etch very deeply and repolish afterwards. His reagent, like all other cupric reagents, acts upon certain parts, dissolving portions of them; therefore, on slightly repolishing, the parts least acted upon take a bright polish, whilst the hollow places from which the metal has been removed by the etching remain dark.

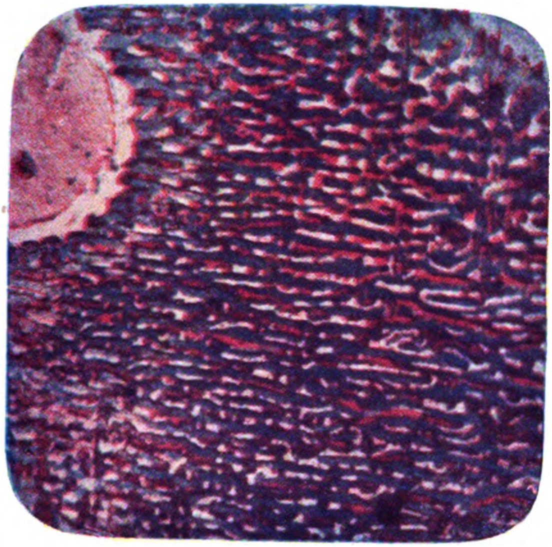
Mr. Harry Brearley, when discussing Rosenhain and Haughton's paper on their new etching reagent ([48]), suggested the use of an extremely dilute solution of ferric chloride in the neutral or slightly acidified condition. Judging from the illustration accompanying his remarks it would appear that his reagent gives the same indications as the cupric reagents, but there can be little doubt that if the parts etched are invariably darkened by a deposit of copper, the contrasts by use of the cupric reagents are more pronounced. Brearley's ferric-chloride reagent seems to give similar results to those obtained years ago by myself with exceedingly dilute acid solutions.

OTHER ELEMENTS THAN PHOSPHORUS GIVE SIMILAR INDICATIONS.

The action of the copper etching reagents depends on the relative solubility of different parts of the metal in dilute acids. The parts most soluble are the first to decompose the copper salt. As iron or steel always contain some parts more soluble than others, the copper appears first on the more soluble portions. If one part contained 0·01 per cent. phosphorus and the other 0·02 per cent., the copper would appear first on the former; similarly, if one part contained 0·1 per cent. and another 0·2 per cent., it would precipitate first on the purer part. The method therefore gives only differential and not actual results, with this difference, however, that the higher the phosphorus the slower the attack.

In seeking to determine whether other elements than phosphorus in variable solid solution would give similar indications, alloys of iron with nickel, copper, arsenic, chromium, tin, and antimony were prepared. The reagent proved that

PLATE XXI



No. 1.

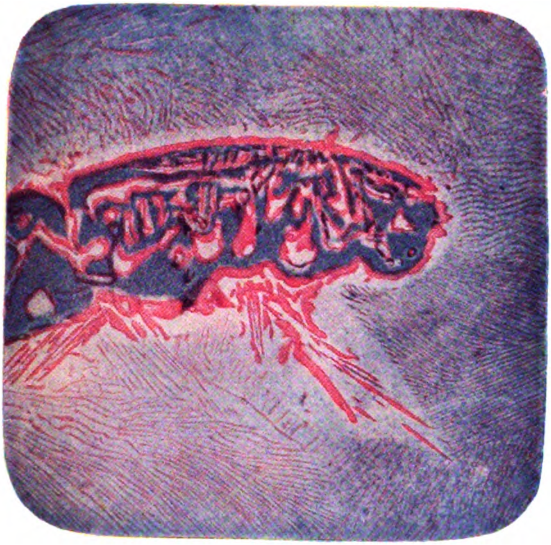
Normal Structure of the Ternary Eutectic of Iron, Carbon, and Phosphorus.
Magnified 330 diameters. Heat tinted.

Red = Iron carbide.
Purple = Iron phosphide.
White = Iron containing some phosphorus in solid solution.

Analysis.

	Per Cent.
Iron	91·19
Carbon	1·92
Phosphorus	6·89
	100·00

This and the other coloured plates were reproduced from colour photographs obtained on Lumière autochrome plates.

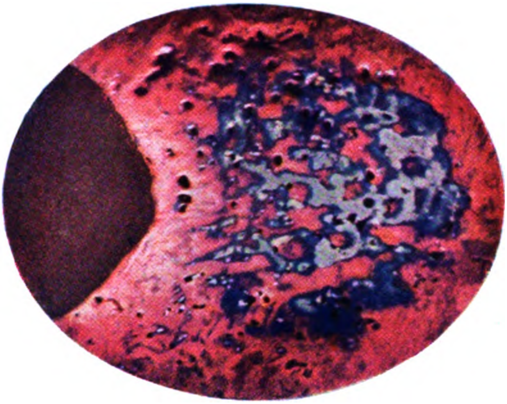


No. 2.

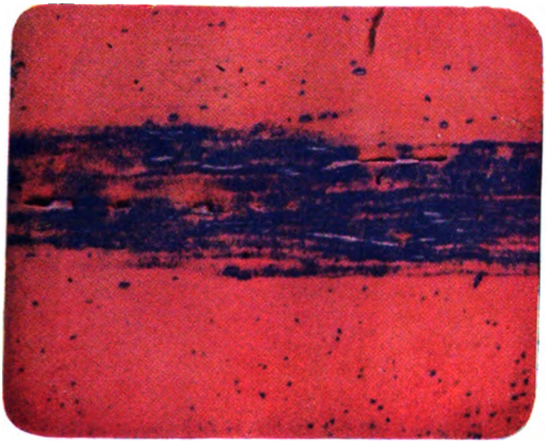
Part of Bear from an Ormesby Blast-furnace, containing an inclusion of Segregated Ternary Eutectic.

Magnified 200 diameters. Heat tinted.

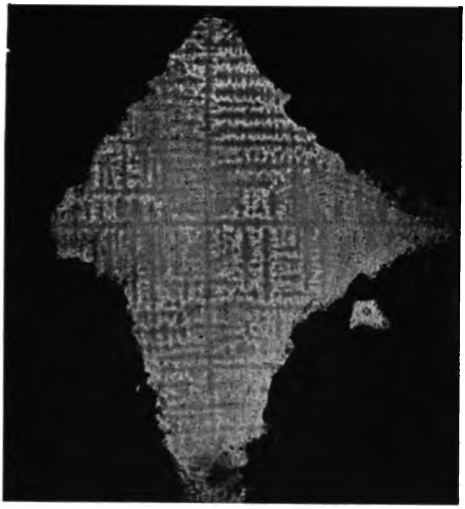
Red = Iron carbide.
Blue = Iron phosphide.
White = Iron containing some phosphorus in solid solution.



No. 4.
A Blowhole in a Soft Steel Ingot, partially filled with Metal rich in Sulphur and Phosphorus.
Magnified 20 diameters.
Blue = Rich in phosphorus.

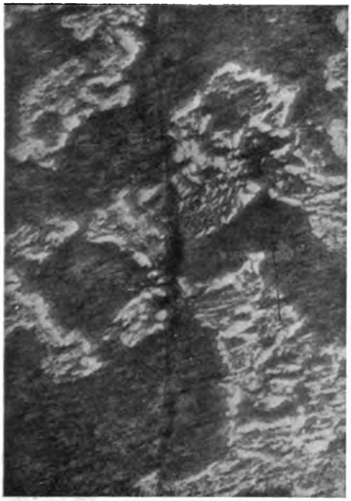


No. 5.
A Blowhole Segregation after extension by rolling to a 2-inch Billet.
Magnified 330 diameters.
Red = Pure steel.
Blue = Rich in phosphorus.
White streaks = Sulphides.

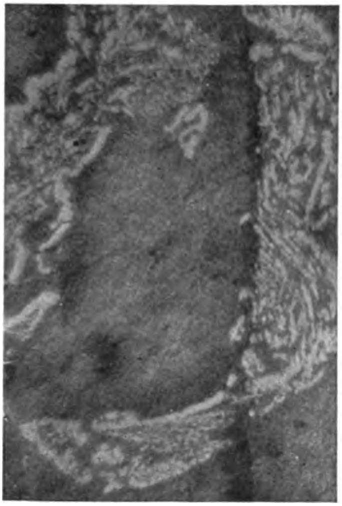


No. 3.

Section of a large crystallite from a steel ingot, showing primary crystallite skeleton dark and trapped impure metal. Magnified 1¼ diameters. Etched with the cupric reagent.



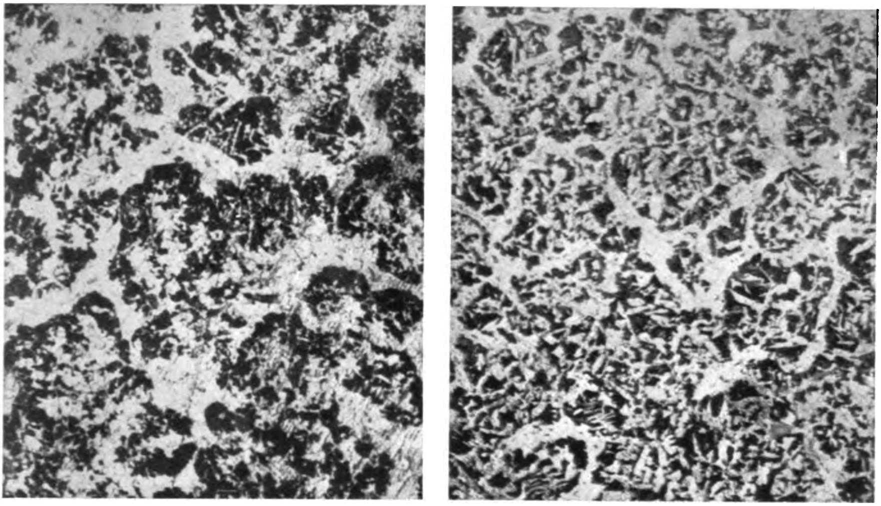
No. 6.



No. 7.

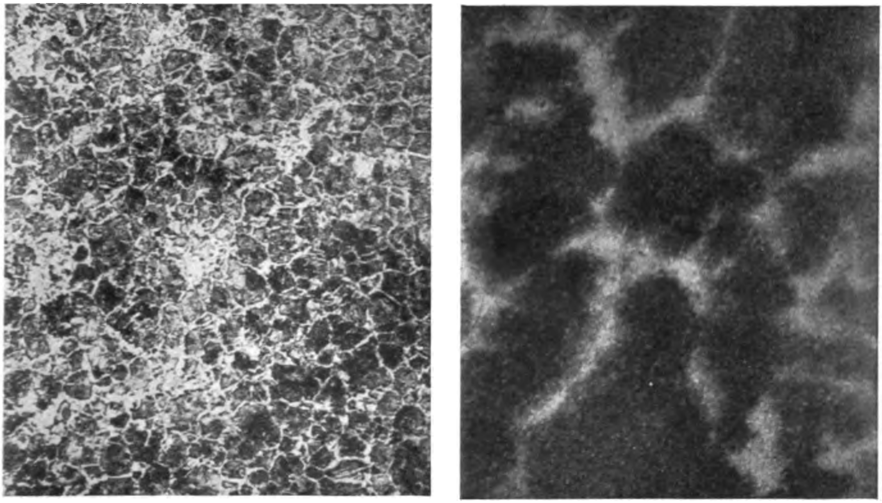
Mildly cemented Swedish Bar, showing slag lines running through ferrite and pearlite. Etched with the cupric reagent.

PLATE XXV



(*a*) As received.
Etched with acid. Magnified 50 diameters.

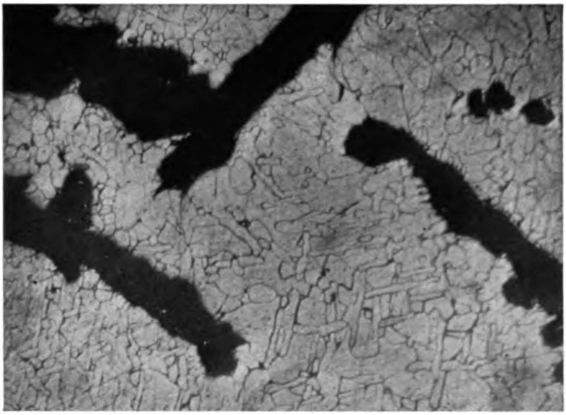
(*b*) Reheated to 950° and slowly cooled.
Etched with acid. Magnified 50 diameters.



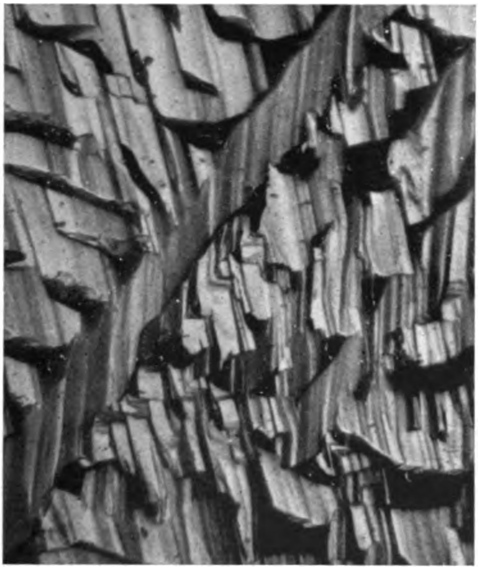
(*c*) Reheated to 850° and cooled in air.
Etched with acid.
Magnified 50 diameters.

(*d*) Reheated to 800° and quenched.
Etched with the cupric reagent.
Magnified 50 diameters.

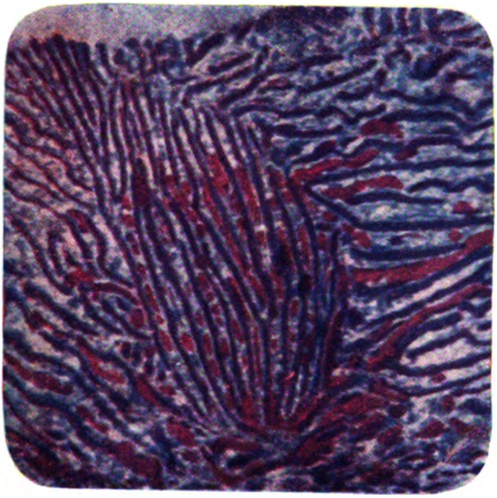
No. 8.—Cast steel—Carbon, 0·3; Phosphorus, 0·045; Tenacity, 35·7 tons; Elongation, 16 per cent.; Bend, 90°.



No. 9.—Blast-furnace Bear containing 0·43 per cent. Phosphorus in solid solution. Magnified 50 diameters.



No. 11.—Iron Phosphide crystallised out of Iron. Magnified 330 diameters.



No. 10.

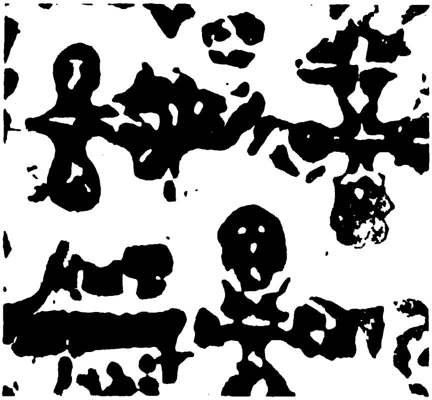
Ternary Pearlite Fringe formed on Carburising by Cementation an Alloy containing about 2 per cent. Phosphorus and 98 per cent. Iron. The fringe represents the extreme point of carbon penetration.

Magnified 330 diameters.

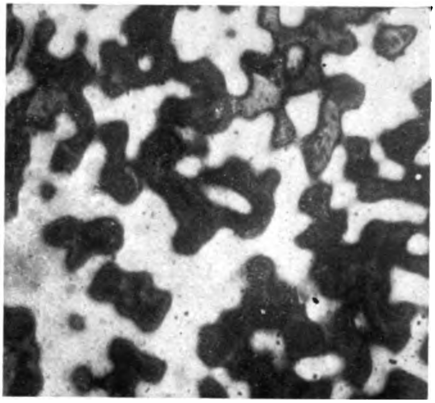
Red = Iron carbide.
Blue = Iron phosphide.
White = Iron containing some phosphorus in solid solution.

The probable composition is, namely:—

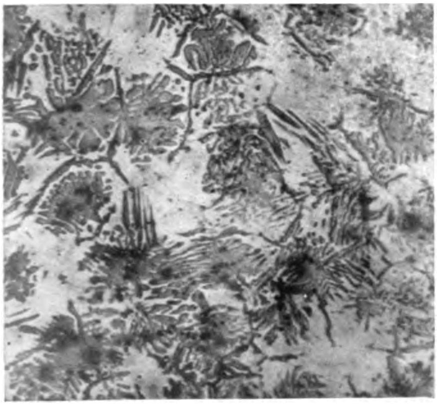
	Per Cent.
Iron, &c.	97·2
Carbon	0·8
Phosphorus	2·0



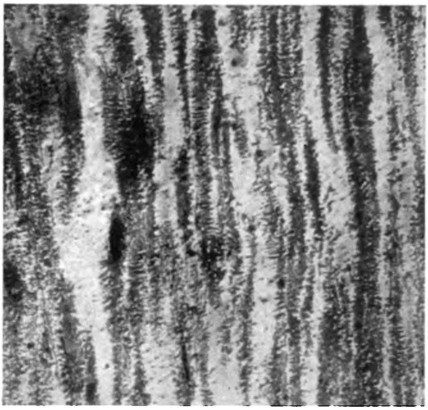
No. 12.
(*a*) Phosphorus, 1·2 per cent.; Carbon, 0·04 per cent. Magnified 50 diameters.



No. 13.
(*b*) Phosphorus, 1·2 per cent.; Carbon, 0·04 per cent.—another part. Magnified 50 diameters.

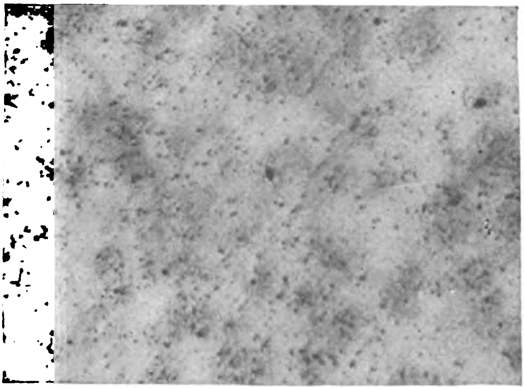


No. 14.
(*c*) Phosphorus, 0·4 per cent.; Carbon, 0·04 per cent. Magnified 50 diameters.



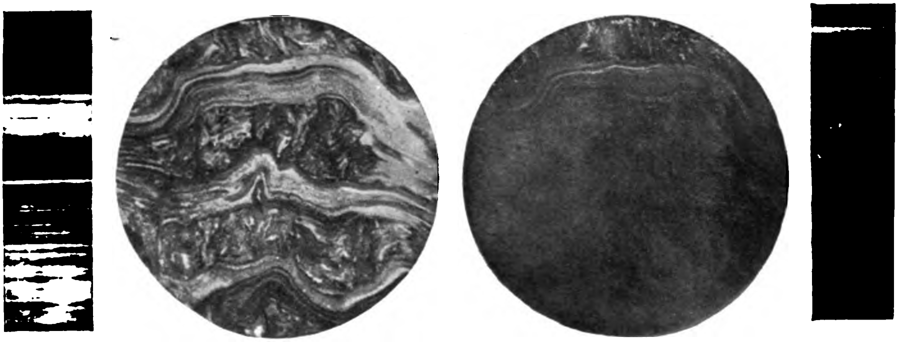
No. 15.
(*d*) Phosphorus, 0·4 per cent.—hammered flat. Magnified 50 diameters.

"After-blow" metals from a basic-lined converter. Etched by the cupric reagent. Magnified 50 diameters. The dark parts contain least phosphorus.



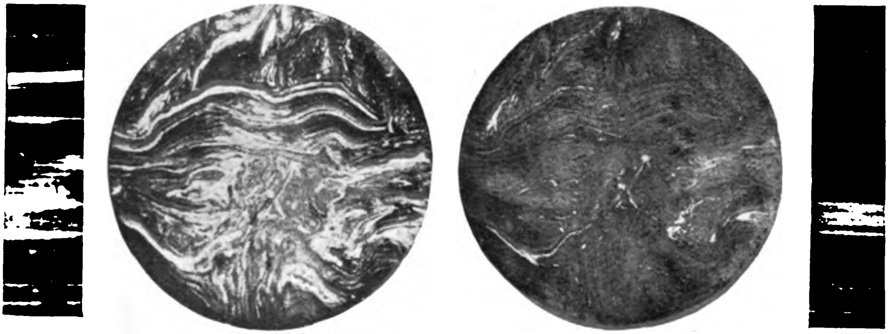
No. 16.
Phosphorus, 0·03 per cent. As cast. Magnified 50 diameters.

PLATE XXIX



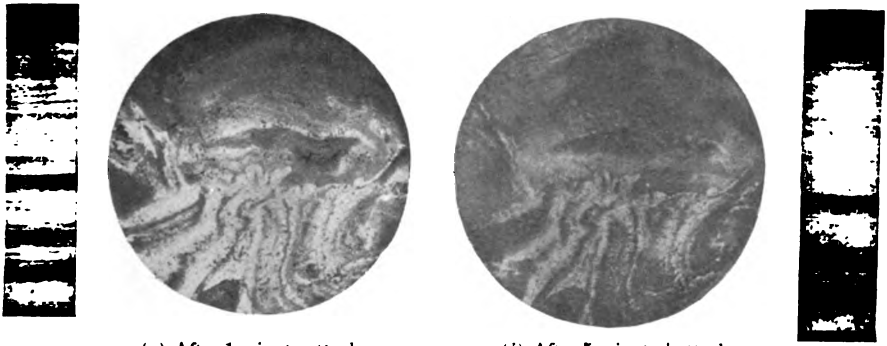
(*a*) After 1 minute attack. (*b*) After 5 minutes' attack.

No. 17.



(*a*) After 1 minute attack. (*b*) After 5 minutes' attack.

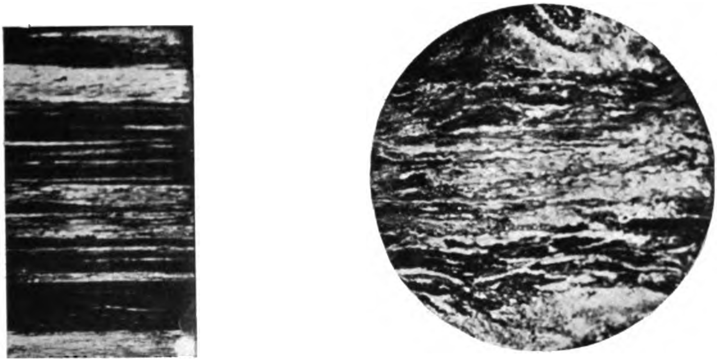
No. 18.



(*a*) After 1 minute attack. (*b*) After 5 minutes' attack.

No. 19.

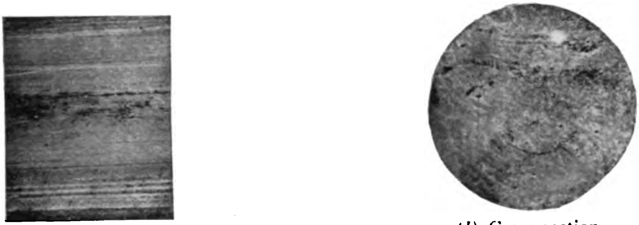
BEST YORKSHIRE IRONS. Magnified 2 diameters.



(*a*) Longitudinal section. (*b*) Cross section.

Cleveland Wrought Iron—Phosphorus, 0·3 per cent.

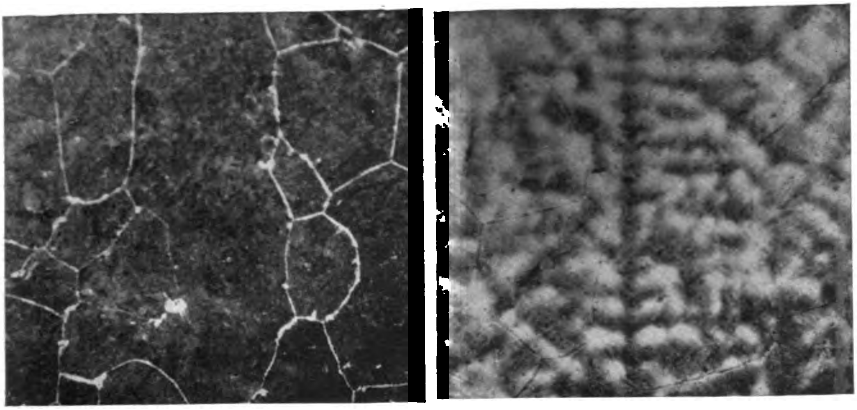
No. 20.—Ten minutes' attack with cupric reagent. Magnified 2 diameters.



(*a*) Longitudinal section. (*b*) Cross section.

Swedish Bar.

No. 21.—Half a minute attack.



(*a*) Rail ingot. Etched with acid. Magnified 50 diameters.

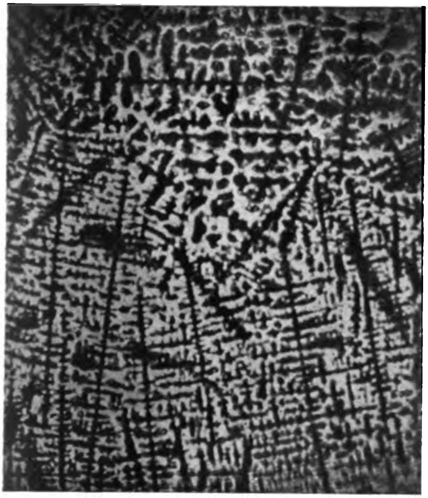
(*b*) Rail ingot. Etched with cupric reagent. Magnified 50 diameters.

No. 22.

No. 24.—Cross section of a steel rail head containing 0·07 per cent. Phosphorus. Natural size. Etched with dilute acid.

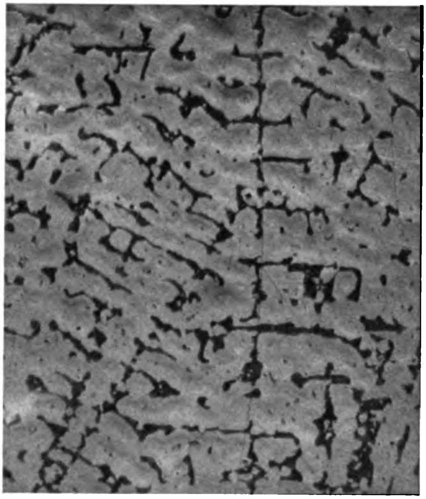
No. 25.—Cross section of a rail head containing 0·03 per cent. Phosphorus. Natural size. Etched with the cupric reagent.

PLATE XXXI



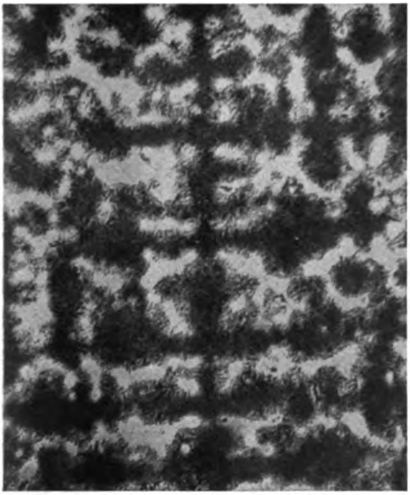
(*a*) Steel—Carbon, 0·17; Phosphorus, 0·39; Silicon, 0·18. Etched with cupric reagent.

Magnified 5 diameters.



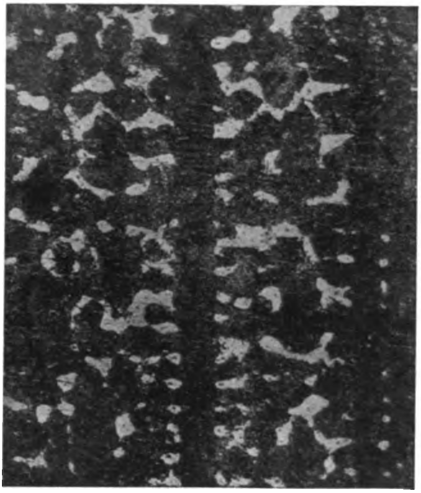
(*b*) Steel—Carbon, 0·17; Phosphorus, 0·39; Silicon, 0·18. Etched with acid.

Magnified 50 diameters.



(*c*) Steel—Carbon, 0·17; Phosphorus, 0·39; Silicon, 0·18. Etched with cupric reagent.

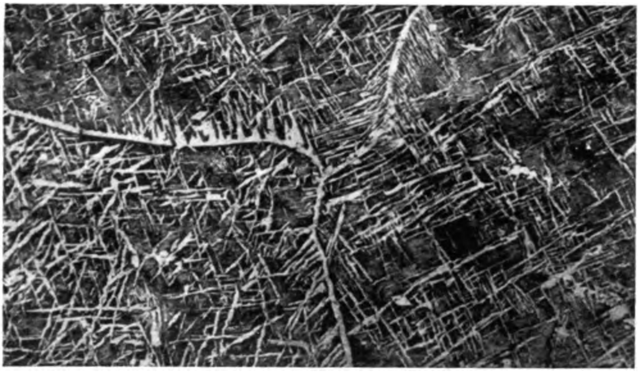
Magnified 50 diameters.



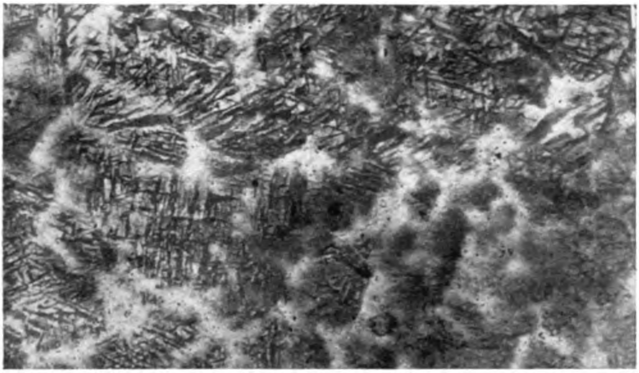
(*d*) Steel—Carbon, 0·17; Phosphorus, 0·39; Silicon, 0·18. Etched with cupric reagent—10 minutes.

Magnified 50 diameters.

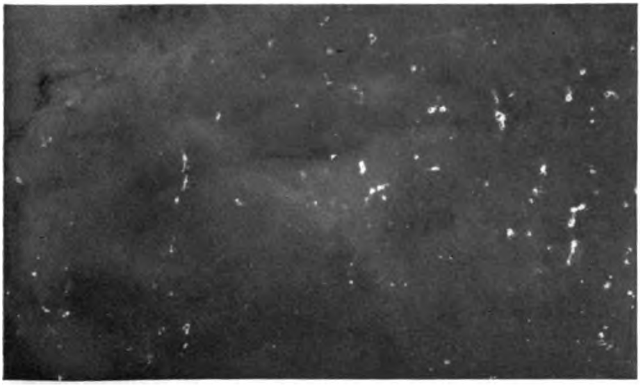
No. 23.



(*a*) Etched with acid. Magnified 50 diameters.



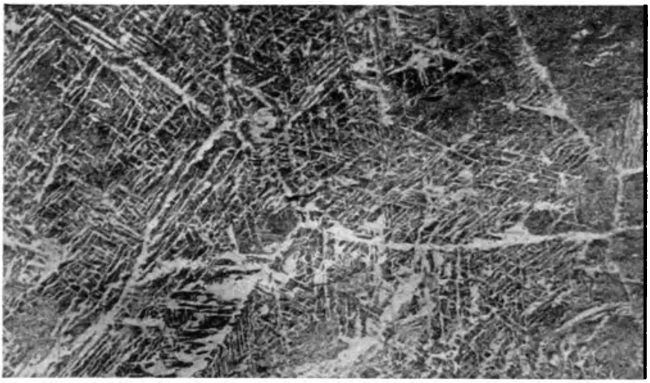
(*b*) Etched with cupric reagent. 1 minute attack.



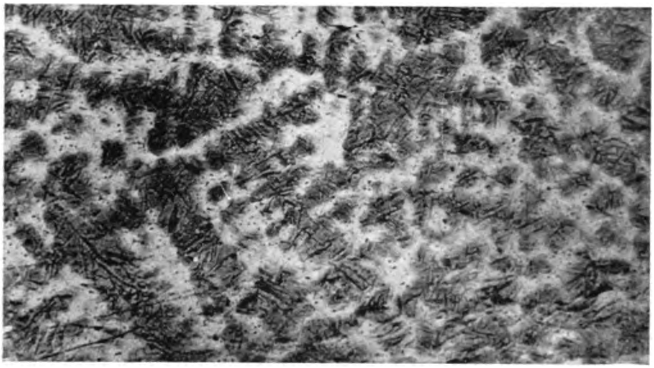
(*c*) Etched with cupric reagent. 5 minutes' attack.

No. 26.—Crucible steel ingot. Carbon, 0·45 per cent.; Phosphorus, 0·012 per cent.

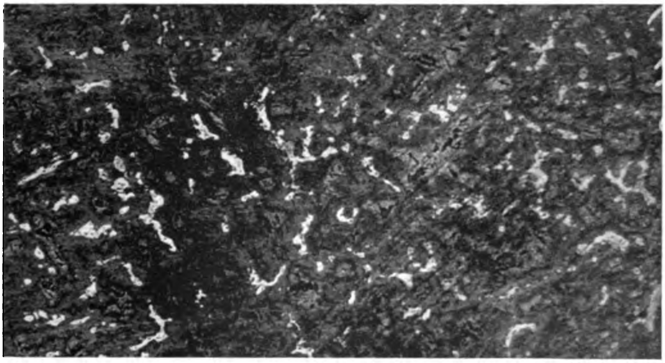
PLATE XXXIII



(*a*) Etched with acid.



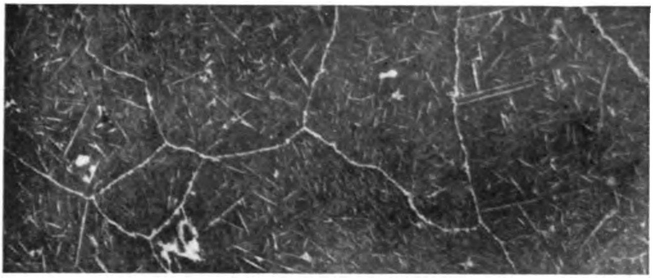
(*b*) Etched with cupric reagent. 1 minute attack.



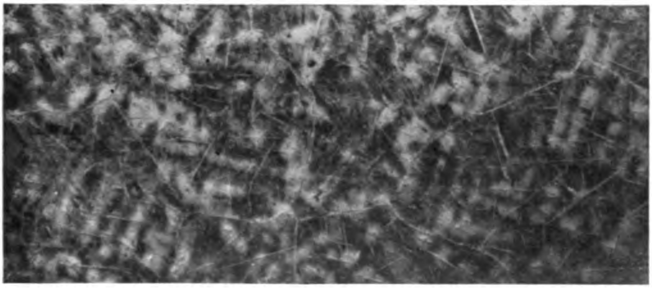
(*c*) Etched with cupric reagent. 5 minutes' attack.

No. 27.—Crucible steel ingot. Carbon, 0·45 per cent.; Phosphorus, 0·08 per cent.

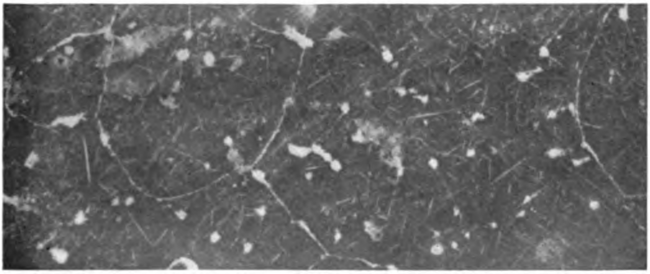
PLATE XXXIV



(*a*) Etched with acid.



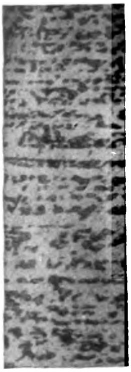
(*b*) Etched with cupric reagent. 1 minute attack.

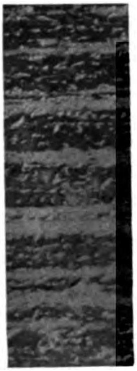


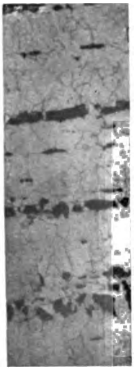
(*c*) Etched with cupric reagent. 5 minutes' attack.

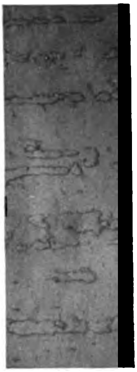
No. 28.—Crucible Steel Ingot. Carbon, 1·2 per cent.; Phosphorus, 0·012 per cent.

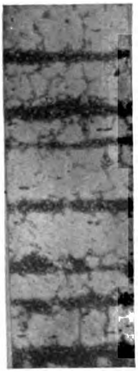
PLATE XXXV

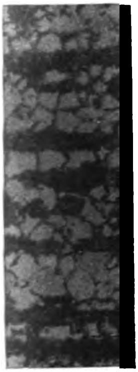

(*a*) Etched with acid.

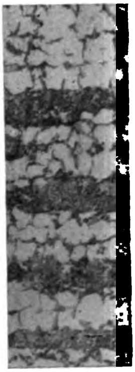

(*b*) Etched with new reagent.

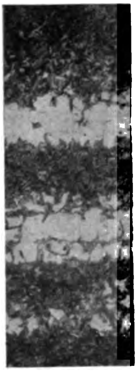

(*c*) Annealed.


(*d*) Quenched from 750° C.

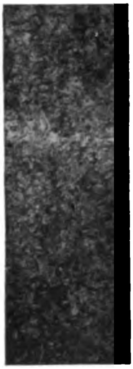

(*e*) Heated to and cooled from 790° C.

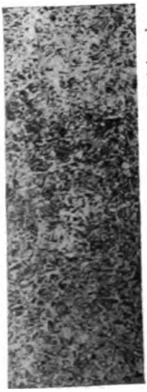

(*f*) Heated to and cooled from 800° C.

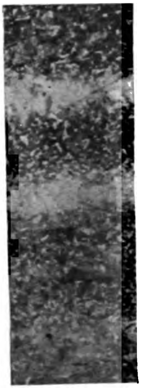

(*g*) Heated to and cooled from 850° C.

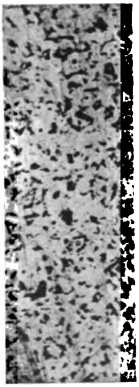

(*h*) Heated to and cooled from 890° C.

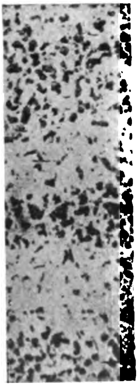
(*i*) Heated to and quenched from 900° C.

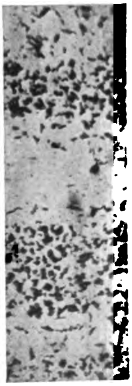

(*j*) Heated to and quenched from 920° C.


(*k*) Heated to 1000° C. and cooled in air.
Etched with acid.


(*l*) Heated to 1000° C. and cooled in air.
Etched with cupric reagent.

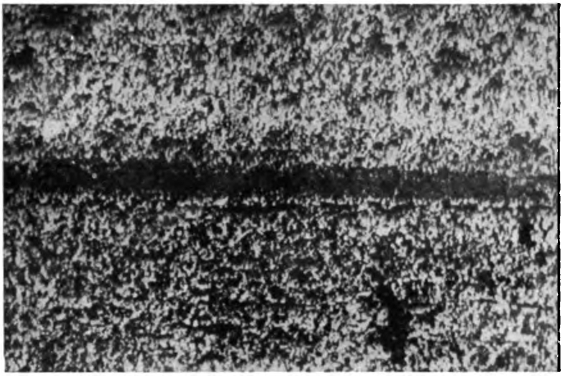

(*m*) Heated to 1000° C. and slowly cooled.


(*n*) Heated to 1000° C. and cooled more slowly.


(*o*) Heated to 1000° C. and cooled still more slowly.

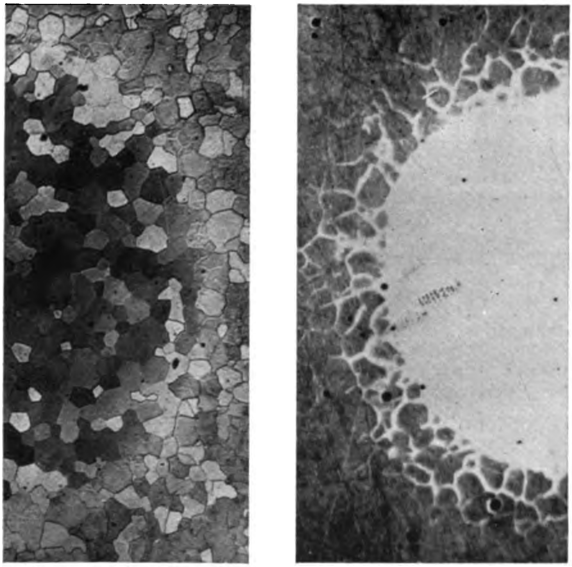
No. 29.—Soft steel plate.
Photos (*a*) and (*e*) to (*k*), and (*m*) to (*o*) etched with acid.

PLATE XXXVI



No. 30.

Bar with phosphorus layer, cemented in blast-furnace gas. Magnified 50 diameters.



(*a*) Etched, then heat-tinted to brown and pale yellow.

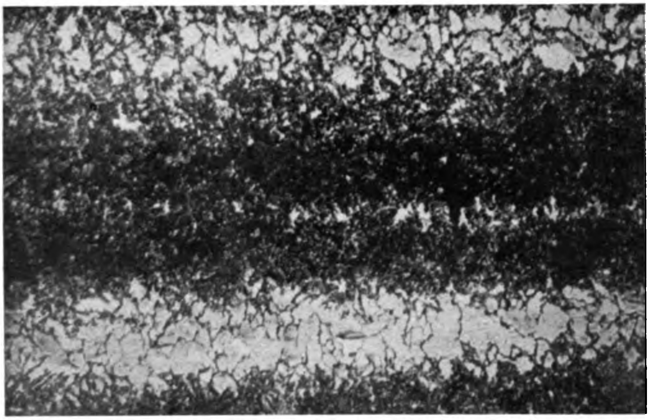
(*b*) Same area after repolishing attacked by cupric reagent.

No. 31.

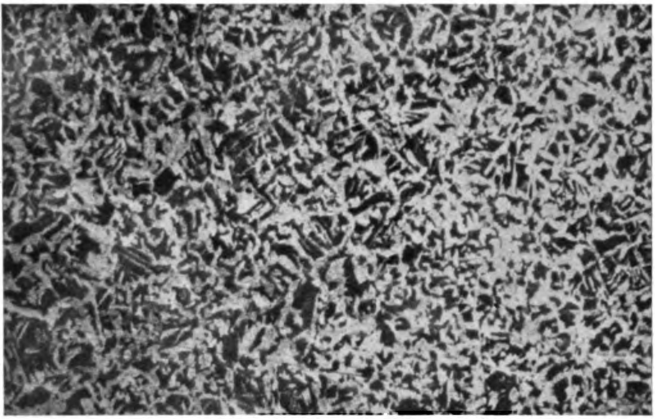
Iron with a spot rich in Phosphorus.

UofM

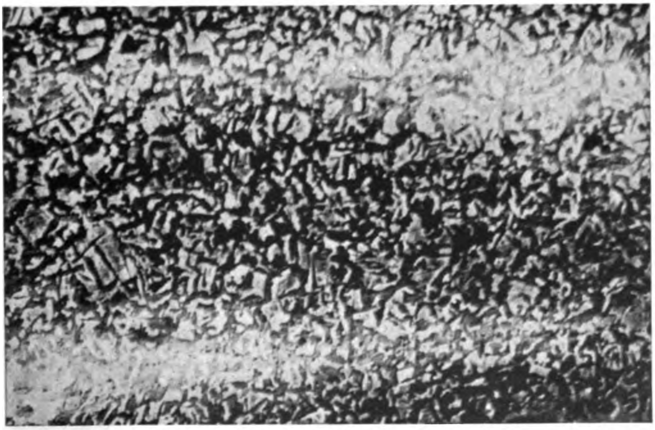
PLATE XXXVII



(*a*) As received.



(*b*) Heated to 950° C. Etched with acid.



(*c*) Same as (*b*). Etched with cupric reagent.

No. 32.—Ghost lines in large forging. Magnified 50 diameters.

MnU

each of the added elements when in appreciable proportion is unequally distributed in the alloys, for the metals contain parts more soluble in dilute acid than others and precipitate copper from the alcoholic reagents the more rapidly.

A rail containing 1 per cent. copper gave indications of unequal distribution, and on testing it was found to contain on the outer part of the head 0·79 per cent. copper, and in the centre 1·373 per cent., proving that copper does segregate just like phosphorus and sulphur, an important result, for there is some conflict of opinion on the question. The rail I examined contained about 0·6 per cent. carbon, and it seems probable that this may have some influence, for I have shown in a previous paper ([52]) that while pure iron and copper alloy in all proportions, the presence of much carbon leads to the production of two conjugate solutions which separate from each other before solidification occurs, one containing an excess of copper, the other an excess of iron.

It may be accepted that mixtures of metals or metalloids which are eutectiferous or tend to form conjugate solutions or to separate into parts, one of which contains more of one of the constituent elements than the other, will not be homogeneous and will have parts more soluble than the other portions.

Carbon and iron yield a eutectic and eutectoid and separate into iron and carbide of iron. Copper deposits on the iron in advance, leaving the carbide white.

Martensite embedded in and surrounded by iron, if as hardenite, does not readily precipitate copper, but if diluted as it is in steels containing about 0·13 per cent. carbon quenched from 850° C., copper is liable to be deposited equally on the free iron and martensite.

Alloys of nickel and iron contain primary crystallites differing in solubility according to the rates at which they solidify.

Tin and iron form conjugate solutions, and the tin-iron liquid which is last to freeze in steel is less soluble than the primary crystallites. Some of the chromium nickel carbon alloys, etched by the cupric reagent, might easily be mistaken for steel very high in phosphorus. It is important that these facts should be stated and the limitations of the cupric reagent be recognised, for unless the metallographist is warned of this, he will be liable to come to wrong conclusions, and condemn even the very best steel when he applies it.

In conclusion, I think it must be admitted that the alcoholic cupric reagents of Rosenhain and Haughton, my own, and others, are of great value in detecting irregularities in commercial carbon steels and irons.

I acknowledge with gratitude the kind co-operation of the following gentlemen in the prosecution of my researches:—

Dr. L. J. Spencer, of the British Museum; Professor H. C. H. Carpenter; Professor C. A. Edwards; Mr. J. M. Gledhill; Dr. J. O. Arnold; Mr. H. Brearley; Mr. E. H. Saniter; Messrs. J. L. & H. A. Potts and assistants of Messrs. J. H. Andrew & Co., Ltd.; Mr. J. M. Parkin of Messrs. Hobson, Houghton & Co., Ltd.; Messrs. T. Sorby & Sons, Ltd.; Messrs. Wm. Beardmore & Co., Ltd.; Mr. W. H. Cathcart (Glasgow); Dr. A. Cooper and Mr. C. H. Ridsdale; Mr. A. O. Cochrane and staff of Messrs. Cochrane & Co., Ltd.; Mr. G. Ritchie, Mr. F. Outhwaite, and Mr. D. Sillars of Messrs. Bolckow, Vaughan & Co., Ltd.; Mr. W. Shaw of Messrs. W. Shaw & Co., Ltd.; Messrs. Dorman, Long & Co., Ltd.; Mr. B. Talbot; Mr. F. Fremont; Mr. T. C. Hutchinson and staff of Messrs. The Skinningrove Iron Co., Ltd.; Mr. C. J. Bagley, and, finally, of my own assistants.

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DISCUSSION.

Dr. H. C. H. **Carpenter** (Royal School of Mines) said Dr. Stead's communication, which he had read with great pleasure and profit, was really a series of papers, and no doubt different members would be interested in different points. He himself was particularly interested in the scientific interpretation of what happened in the cooling of the alloys from the liquid condition to the ordinary temperature. He might deal later with that aspect of the question, and in the meanwhile he wished to express his conviction that Dr. Stead spoke with peculiar authority on any subject connected with the presence of phosphorus in iron and steel.

Dr. W. H. **Hatfield** (Sheffield) said that Dr. Stead's original paper on Phosphorus and Iron, published before the Institute in 1900, was really the chief source of information on the subject, and he was sure that the present paper would rank with the first, the two together constituting an excellent work of reference. Dr. Stead discussed the throwing out of carbon by the phosphorus, and in that connection it was of interest to study the ternary eutectic of iron-phosphorus and carbide. That eutectic when molten consisted of a solution of carbide and phosphide in iron, and if a cooling curve of the material were taken it would, if his (Dr. Hatfield's) memory served him well, be found that the phosphide was thrown out of solution on freezing at a temperature just below 1000° C., leaving a solid solution of carbide in iron which precipitated its carbide on reaching the Ar1 point. That was an instance where the carbide eliminated the phosphide, but it was not quite clear that in low phosphorus alloys some phosphide would not be carried in solid solution with the carbide down to the recalescence point. There were several points still obscure as regards the relationship existing in the ternary system with different temperatures, and more data would be necessary before a final verdict could be given on problems relating thereto. He was much interested in Dr. Stead's "phosphorus" etching reagent. Dr. Rosenhain, last year, had given an interesting paper upon a similar reagent. At that time he (Dr. Hatfield) tried the latter reagent somewhat exhaustively without useful result. A fortnight previous to the meeting, Dr. Rosenhain had been to Sheffield, and had given a most interesting lecture. One of his latter micrographs was in illustration of a well-known defect which was observed, at times, even in Sheffield steel. Fortunately that defect and its cause were too well known, and to state, as Dr. Rosenhain had done, that it was due to phosphorus as indicated by his reagent, was inaccurate. However, Dr. Rosenhain's certainty upon the cause led him (Dr. Hatfield) to make further experiments, and, having ascertained the composition of Dr. Stead's reagent, he forthwith prepared a quantity of the two solutions for a comparison of the results. A whole range of materials was examined with the reagents with interesting but inconclusive results. Dr. Stead's final words in concluding his paper were to the point. "In conclusion, I think it must be admitted that alcoholic cupric reagents of Rosenhain and Haughton, my own and others, are of great value in detecting irregularities in commercial carbon steels and iron." What irregularities, however, did they indicate? It was possible with such reagents to obtain all kinds of results, and whilst in the hands of the originators useful comparative figures might be obtained, it was very dangerous that reagents like those should be used widely until a more complete understanding of the results could be obtained. Some of his (Dr. Hatfield's) micrographs obtained by means of the two reagents were reproduced in plates, and whilst the original prints were at 120 magnification it should be borne in mind that the samples had also been examined at much lower powers as well as macroscopically. It was thought that to study a Bessemer No. 1 iron containing 0·03 per cent. phosphorus and a Lincolnshire foundry pig containing 1·35 per cent. phosphorus with both reagents would form a good test. The results were seen in Plate XXXVIII. Figs. 1 and 2 showed the results obtained with Dr. Rosenhain's solution, both sections being etched for the same period in the same dish. The results appeared instructive, and Fig. 2 would indicate that the solid solution surrounding the phosphide (post eutectic) was high in phosphorus. Figs. 3 and 4 were the results obtained from the same materials treated under the same conditions by Dr. Stead's solution. The reagent would appear to have brought out a lack of homogeneity existing in the solid solution in the Bessemer iron (Fig. 3). That could hardly be due to phosphorus, and he would suggest that it might be due to unequal distribution of silicon. The areas coincident with the graphite etched darkest, and would be expected to contain less silicon than the other portions of the iron, the reason being that his (Dr. Hatfield's) experiments had always shown the carbide to contain less silicon than the matrix, and hence the iron resulting from the breaking down of that constituent into graphite would naturally also contain less silicon. Fig. 4 would indicate that according to Dr. Stead's solution the phosphide did not remain in solution, but was all present as eutectic phosphide. It would be seen that those results were much at variance with each other. The micrographs shown in Figs. 5 to 8 were obtained from two white cast irons which varied only in their phosphorus content, one containing 0·04 per cent., whilst the other had so high a percentage as 0·83. In that instance little intelligible information was obtained from either reagent, and it was obviously a case, as indicated by Dr. Stead, where the carbide obscured the phosphide. Fig. 7 was of interest in so far as it appeared to bring out some primary crystals (the dark etching areas). Having tried pig irons and cast irons, it was decided to try some steels. Figs. 9, 10, and 11, Plate XXXIX., indicated the structures obtained by etching a steel casting of very low phosphorus content with picric acid in alcohol, Rosenhain's reagent and Stead's reagent respectively. The black blobs, arising from the sulphide specks, produced by Dr. Rosenhain's reagent were the predominating feature. Fig. 14 illustrated the etching effect of Dr. Stead's solution on a 1·75 per cent. carbon steel low in phosphorus. It would be seen that the discrimination was simply made between the pearlite (dark) and the cementite carbide (white). Fig. 15 was of interest because it clearly showed that when ferrite crystals of like composition were treated in juxtaposition by Dr. Stead's reagent, some would take a deposit, some would not, and others did so in varying degrees. Figs. 12 and 13 showed the structures obtained by etching a sample of malleable cast iron with both reagents. Structurally the material really consisted of pearlite and ferrite (phosphorus 0·04 per cent.), but it would be seen that whereas the laminated pearlite carbide was left white by Stead's reagent, Rosenhain's reagent brought out, as the chief feature, the blobs, occurring presumably in sulphide centres. He thought those results were of sufficient interest to bring before the Institute, and he still believed it might be possible that reagents would be finally devised which would give definite information as to the distribution of elements and compounds in solution in iron. Dr. Stead's paper contained a mass of data and information that could not but prove of great use to iron and steel metallurgists, and he thought the members were much indebted to Dr. Stead for the time and thought he had always given to that particular field of research.

Professor H. **Le Chatelier**, Member of Council, said he was astonished that, in view of the wonderfully complete researches which Dr. Stead had already published, he had been able to make any fresh discoveries in that direction. He (Professor Le Chatelier) was specially interested in the new cupric reagent, revealing the unequal distribution of the phosphorus. He thought, in that connection, that he might describe a method of etching which had given very sharply defined results in revealing isolated stains, due to phosphide. It consisted in placing the sample in a solution of caustic soda, and connecting it up with the anode of a battery. The phosphide was vigorously attacked, and became blackened, whereas the cementite was not affected. He believed, generally speaking, that electrolytic methods would be more and more employed in microscopic metallography. They had the great advantage of enabling the intensity of the etching to be controlled at will much more easily than could be done by changing the nature or the concentration of the solutions. With copper alloys, that method was exceedingly easy to use and gave absolutely constant results. That was not, generally speaking, the case with iron, owing to the phenomena of polarisation, which rendered the reactions very irregular. There were, however, cases, such as that of the phosphide, where the action became very uniform.

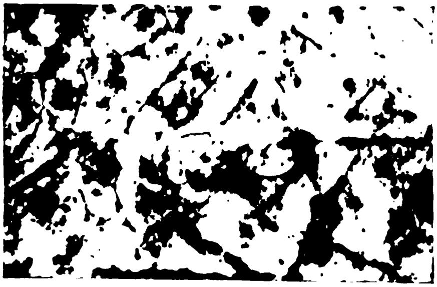

Fig. 1.—Bessemer No. 1 Pig Iron. Phosphorus, 0·03 per cent. Etched (Dr. Rosenhain's reagent). Magnified 120 diameters.

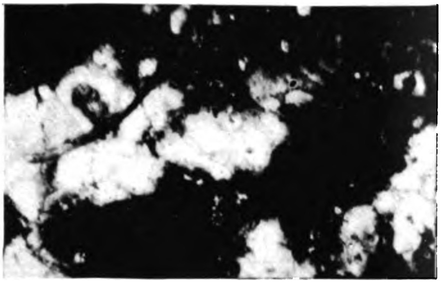

Fig. 2.—Lincolnshire Pig Iron. Phosphorus, 1·35 per cent. Etched (Dr. Rosenhain's reagent). Magnified 120 diameters.

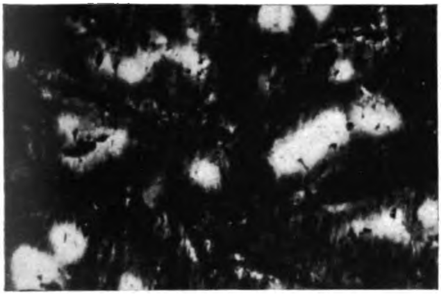

Fig. 3.—Bessemer No. 1 Pig Iron. Phosphorus, 0·03 per cent. Etched (Dr. Stead's reagent). Magnified 120 diameters.

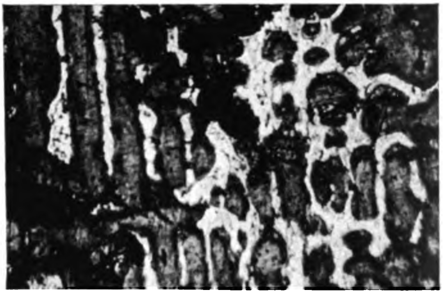

Fig. 4.—Lincolnshire Pig Iron. Phosphorus, 1·35 per cent. Etched (Dr. Stead's reagent). Magnified 120 diameters.

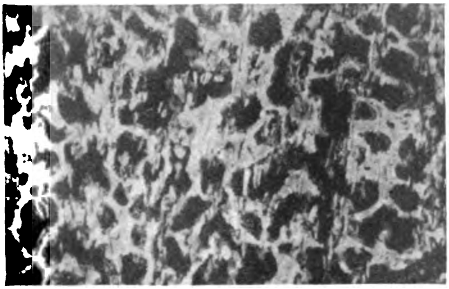

Fig. 5.—White Cast Iron. Phosphorus, 0·04 per cent. Etched (Dr. Stead's reagent). Magnified 120 diameters.

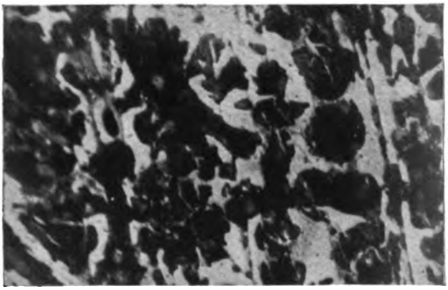

Fig. 6.—White Cast Iron. Phosphorus, 0·83 per cent. Etched (Dr. Stead's reagent). Magnified 120 diameters.

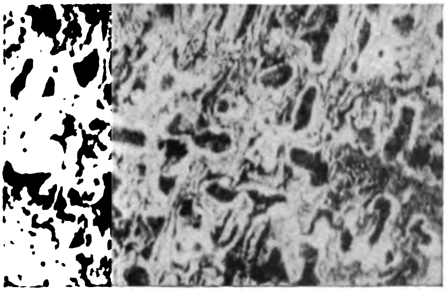

Fig. 7.—White Cast Iron. Phosphorus, 0·04 per cent. Etched (Dr. Rosenhain's reagent). Magnified 120 diameters.

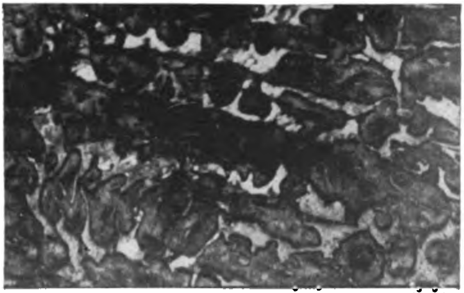

Fig. 8.—White Cast Iron. Phosphorus, 0·83 per cent. Etched (Dr. Rosenhain's reagent). Magnified 120 diameters.

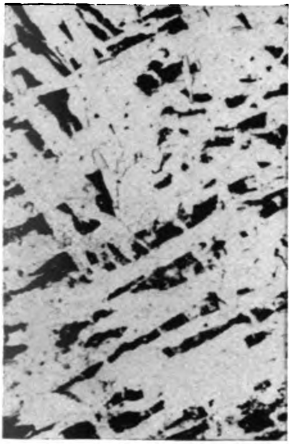

FIG. 9.—Etched (picric in alcohol).

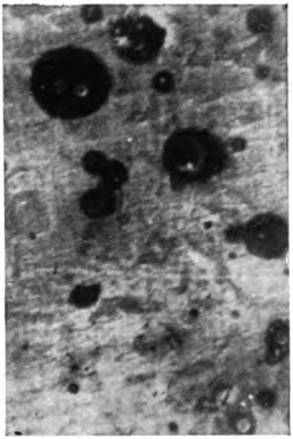

FIG. 10.—Etched (Dr. Rosenhain's reagent).

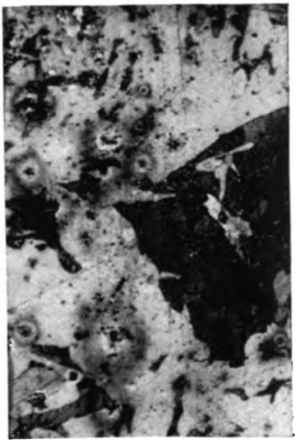

FIG. 11.—Etched (Dr. Stead's reagent).

ELECTRIC STEEL CASTING (Carbon, 0·14 per cent.; Phosphorus, 0·02 per cent.).

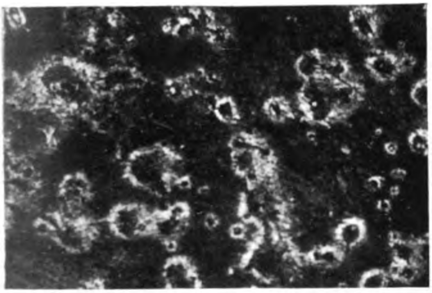

FIG. 12.—Etched (Dr. Rosenhain's reagent).

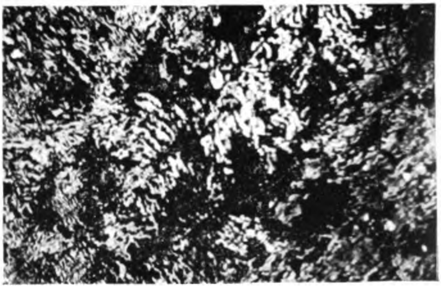

FIG. 13.—Etched (Dr. Stead's reagent).

MALLEABLE CASTING (Phosphorus, 0·04 per cent.).

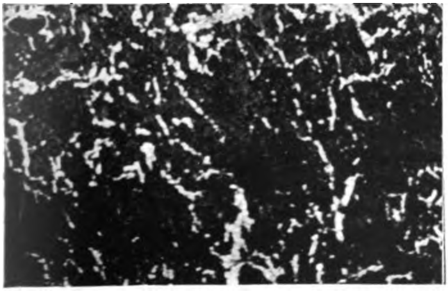

FIG. 14.—Crucible Steel. Carbon, 1·75 per cent.; phosphorus, 0·015 per cent. Etched (Dr. Stead's reagent).

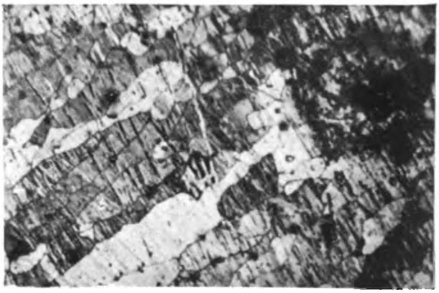

FIG. 15.—Ferrite Band. Phosphorus, 0·03 per cent. Etched (Dr. Stead's reagent)

M 40 U

It was possible, doubtless, to restrict the action of certain energetic reagents, such as copper chloride, in the same way, and thus to obtain similar results by using exceedingly dilute solutions. The sample might be connected either with the cathode or with the anode, according to the circumstances of the case.

Dr. W. **Rosenhain**, F.R.S. (Teddington), said the paper was of extreme value as a summary of the researches and work which Dr. Stead had done, which were scattered through many communications. It was therefore extremely satisfactory to have them in their present form. Everyone knew how much the whole subject was Dr. Stead's own subject, and no one else could have written such a paper. With regard to the new reagents referred to, they were only new in the sense that they had been worked out a little more fully than before. The use of copper solutions for etching pure and simple was fairly old. Osmond certainly used them, but Osmond removed the copper from the surface by wiping it off with the finger. With reference to one of the difficulties of the whole business, and one of the pitfalls into which Dr. Hatfield in particular had fallen, there were two kinds of action which went on together, a dissolving action, of a purely etching nature, and at the same time a deposition of copper. If the conditions were varied in the slightest degree one or other might preponderate, and there would be obtained, sometimes according to the material and sometimes according to the conditions—the temperature he believed influenced the latter—either a preponderance of the etching action, in which case there would be an effect similar to that which would be obtained with picric acid or any other acid, or the deposition effect, which was what was being aimed at when irregularities in dissolved impurities were sought.

Taking first the general question of ghost lines and their injuriousness or otherwise, it was perfectly obvious that as they occurred so universally in practically all commercial steel, it would be ridiculous to say that the mere existence of bands containing more or less phosphorus necessarily rendered the steel bad. He did not think anyone who had any experience would maintain that for a moment. On the other hand, when the bands were numerous, or their width and intensity were excessive, it was necessary to beware of them. First of all there was a concentration of phosphorus in the bands, and consequently there were bands in the steel which might contain several times more phosphorus than the average given by analysis. That in itself was undesirable, and it had a still more undesirable secondary effect. There were alternate layers of two materials which differed in their critical temperatures and in their mechanical properties both cold and hot. Those were being handled together in a sort of multiple sandwich. They were being forged or rolled together, and the result was that they were unequally expanded in the process: the actual geometrical expansion was the same, but their internal behaviour was different, and the result was the production of internal stresses when the material cooled. Possibly there were different thermal expansions which also contributed to that effect. It had been his experience to find that where large plates had cracked spontaneously, the cracking was associated with an unusually large amount of banding and unusually large differences in phosphorus content between successive layers. He could not help thinking that the internal stresses set up in some such way as he had indicated must have something to do with it, but he only suggested that tentatively. There was likewise the effect of the bands on the critical point of the steel. There had been certain differences of opinion, more or less associated with theoretical differences, as to certain critical points. He did not want to raise ghosts in the other sense of the word, but he could not help saying that if two pieces of steel were taken, one of which was completely homogeneous while the other consisted of two materials mixed, one highly phosphoric and the other non-phosphoric, it was quite easily possible for the precise form of the cooling curves and heating curves to differ in the two, in spite of the fact that both observers might be perfectly correct. Those points had not always been considered as much as they might have been. Finally, as Dr. Hatfield had referred to him so repeatedly, he might perhaps be allowed to defend his own reagent for a moment. Dr. Hatfield had fallen into two difficulties—one of them being the fault of the reagent. The fault of the reagent was one which he (Dr. Rosenhain) had recognised long ago, and Dr. Stead too had recognised it, and he thought Dr. Stead had surmounted the difficulty with his reagent, and, if he had, no one would be more pleased and more ready to adopt Dr. Stead's reagent than he (Dr. Rosenhain). With regard to the pitting action, or what Dr. Hatfield had picturesquely described as blobs, wherever there was a sulphide enclosure the ferric chloride reagent did apparently produce violent pitting. Viewed under sufficiently high magnification, the pits were seen and nothing else. The formation of the pits was the fault of the reagent. But if the new cupric solutions were to be judged properly, it was necessary to use extremely low magnifications of 2, 3, or 4 diameters at most when dealing with castings and ingots. Dr. Stead had shown an extremely beautiful specimen, and the specimen he himself had to show was not as beautiful as Dr. Stead's partly because he had not the material at his disposal. His specimen consisted of an etched piece of a steel bloom which had received a certain amount of forging or rolling, and it would be seen that even with the older and probably the less perfect reagent, the dendritic crystals could be perfectly well seen. The amount of distortion which those crystals underwent would depend on the amount of work which had been put on the metal, and it was possible by examining the state of the phosphorus dendrites in any given forging to ascertain how much work had been put on the metal. He had already found in two cases at least that this method gave a very good clue to the causes of serious trouble, thus supplying an interesting and valuable addition to the armament of the metallographer in studying cases of failure. Dr. Hatfield had raised a very important point which Dr. Stead had recognised in his paper, and which he (Dr. Rosenhain) had long recognised and had had under careful investigation. That was whether it was only the phosphorus which affected the action of the reagent. He thought Dr. Stead had hit the nail on the head when he said that the whole question of the rate of deposition of copper depended on the ease of solubility of the ferrite, and consequently on the purity of the ferrite. It did not matter what the dissolved substance was; the purer it was the less soluble the ferrite would be. That was perfectly true, and to that extent Dr. Hatfield's contention was correct, but the whole point was that the separation of dissolved impurities occurred subject to one very serious restriction, and that was that diffusion tended to equalise it. Carbon dendrites were not obtained when the metal was etched with picric acid, simply because the carbon diffused so rapidly that all the lack of homogeneity which occurred in the freezing of a solid solution disappeared long before the steel had cooled in the first place. Phosphorus was one of the most slow diffusing, if not the slowest, of all substances soluble in ferrite, and that was why it was essential in connection with phosphorus and the use of the reagent to consider forged and rolled material and castings separately. Personally he had not, however, dealt with them to any large extent. The matter had to be studied carefully, and Dr. Hatfield's researches were interesting contributions. The whole point was that the reason why the phosphorus dendrites were so interesting and important was because of their persistence, owing to the tardy diffusion of the phosphorus. He believed it would be found that nickel behaved in a somewhat similar manner. Nickel in copper diffused with amazing slowness. In forged stampings of what used to be called "German" silver, there were crystals which contained a solid solution of copper, zinc, and nickel, and even after a very long annealing Mr. Hudson had shown that the nickel remained in dendritic cores; so that nickel was a slow diffusing agent also. The whole subject was one in which he was very much interested, and he was most grateful to Dr. Stead for his contribution and glad to have had the opportunity of saying how much he and others who worked on the subject owed to the researches of Dr. Stead, particularly on phosphorus and iron.

Mr. E. H. **SANITER** (Rotherham) said he, too, deeply appreciated the great work which Dr. Stead had carried out on phosphorus during the last twenty-five years. He was sure that for many years to come it would be felt that the world mainly owed to him its knowledge of the behaviour of phosphorus in steel. It had interested him very much to hear that Dr. Stead had found such a mass of dove-coloured and so-called manganese sulphide, and had been able to analyse it and to find it was a mixture of iron and manganese sulphide and not pure manganese sulphide, as had been rather generally supposed up to the present. With reference to the very interesting discovery made by Dr. Stead of iron which contained little phosphorus in phosphoric working furnaces, an interesting event occurred some years ago when he (Mr. Saniter) was at the Port Clarence Steelworks, where there was a mixer for holding the iron before it went to the steel furnace. In the first place, that mixer was lined with silica brick, and when the lining was taken out it was found that the silica bricks had behaved like sponges and had absorbed the cast iron in all their pores. Unfortunately the cast iron in the bricks was not analysed, but cast iron was found under the silica bricks, and that cast iron was very much lower in phosphorus than the ordinary Cleveland iron. It seemed to him at the time that the porous silica bricks had allowed pure carbide of iron to penetrate through while resisting the passage of the phosphide of iron. He (Mr. Saniter) had not made any trials with the new copper reagent, but he had made one with Dr. Rosenhain's reagent and found nothing but "blobs." As the reagent seemed to be rather delicate to use, he thought it would be very desirable if Dr. Stead would give the most exact information possible for making it aright. In the paper Dr. Stead said that certain salts had to be dissolved in water, but did not give the quantity of water to be used. He also said that it had to be made up to 1000 cubic centimetres with alcohol, but whether methylated spirits or absolute alcohol was not stated. Having regard to the importance of the subject and the rather conflicting results obtained, the most definite information possible should be given. Ghost lines were rather a ticklish subject, and for his part he thought that whether they should be considered dangerous or not was a question of degree. Dr. Stead suggested that by certain heat treatment it was possible to get rid of white ghost lines. Taking the subject only a step further, it might be asked whether a white or a black ghost line was the better or the worse. The explanation given by Dr. Stead of the form of the ghost line with reference to the blowholes must be absolutely correct, but there were ghost lines in steel where there were no blowholes, and such ghost lines called for another explanation. There was no doubt that in that case it was simply the last freezing mother liquor which formed the segregates and the ghost line, but the reason it did so in one steel and not in another from day to day was a mystery. For the identification of dendrites, the phosphorus reagent was probably a useful method, but at the same time it should be pointed out that it was possible to see the dendrites without any copper solutions at all, by getting the steel into an oblique light and viewing it with the naked eye.

Mr. **Ralph Scott** (London) said: On p. 143 of his paper Dr. Stead said: "The large mass of metal, about 500 or 600 tons in weight, in cooling exceedingly slowly, contracted circumferentially and compressed the central portion, which, being in the middle, was the last completely to solidify." He had heard that mentioned two or three times, but had never been able to gather why it should be so. He believed Dr. Stead described the columnar structure as due to pressure exerted on the interior portion of the "bear" by the contraction of the outside. He (Mr. Scott) had been always greatly interested on examining slag heaps in search of artificial minerals, and had obtained some very interesting specimens from them, and he had had many large pieces of metal out of the bottom of open-hearth furnaces to break up and examine, but in none of those cases did he ever find any signs of pressure from the outside; it was always the other way. There were generally a number of cavities, often lined with crystals, for, when metal or slag cooled, the outside skin became set and fixed in dimensions, and the result of slower cooling inside was not pressure from the outside, but rather the reverse, and hollows occurred such as were found in ingots. An ingot was cast, and the outside solidified and formed a skin; the inside of the ingot cooled more gradually and contracted away from the outside skin, which was the cause of piping and unsoundness when solidification was complete. If one could only induce pressure from outside on the interior portion without mechanical aid the difficulty of unsoundness of ingots would be done away with. It would be a good thing if the question of pressure being exerted on a cooling mass by contraction of the outside circumference were more clearly explained.

Professor A. **McWilliam** (Kalimati, India) said that Dr. Stead's papers were so full of matter that it was impossible to do them justice in the time at disposal. If people came to him (Professor McWilliam) on the subject of phosphorus, he invariably told them to go and see what Dr. Stead said about it. There was a point of considerable importance with regard to ghost lines that had not been mentioned, and that was the transverse section, the nature of which was very important. Inspectors had a very anxious time sometimes, much more so than manufacturers believed, in thinking over what it would be fair to reject, and he knew from experience that one of the points that gave them very great anxiety was the question as to what nature and quantity of ghost lines should constitute sufficient reason for rejection of steel. The transverse section needed special investigation, and he would like to know Dr. Stead's views on that subject.

Professor C. A. **Edwards** (Manchester University) thought he could show the great importance of Dr. Stead's work from a practical standpoint by instancing the fact that a year or so ago a casting came before his (Professor Edwards') notice which had to be turned up. A certain section of the casting resembled Fig. 1*a*. Whilst in the lathe the turner found that the tool would not touch the edge at A. Every other part of the casting could be turned quite readily, but under no conditions whatever could that surface be turned. Pieces were broken off at A, and underneath were found very large numbers of small blowholes. That immediately made him think of Dr. Stead's work on blowholes, and he had them analysed, as well as an analysis of the casting. The casting was rather an abnormal steel, containing 0·5 per cent. of carbon along with 0·14 per cent. of phosphorus. The pieces that were broken off contained 0·6 per cent. of phosphorus, and on examining those pieces under the microscope he found that the structure indicated that inside the initial blowholes the phosphorus had been segregated to the extent of at least 10 per cent. of phosphorus. That brought him to the other question of how pressures had the effect of disturbing the equilibrium, because if the steel had been cooled under normal conditions and no blowholes had been formed, the whole of the phosphorus would have been held in solid solution; but owing to the appearance of blowholes and the enormous pressures set up inside of the casting, the equilibrium was removed into another phase-field of the equilibrium line. That, he thought, was rather a good practical example of the importance of studying very carefully the contents of blowholes. In that particular case the blowholes were on the surface of the casting simply because the mould had not been properly dried, the sand being somewhat wet, and the blowholes being formed not from the steel itself but from the mould, and afterwards segregation occurring.

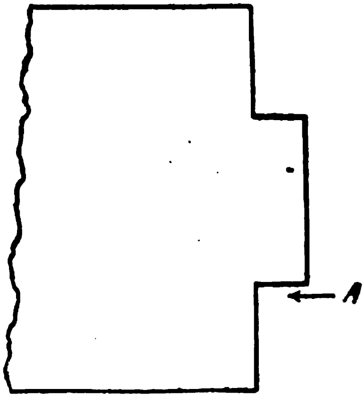

FIG. 1*a*.—Section of Casting with Hard Spot at A.

Dr. **Stead**, in reply, thanked the speakers for their very complimentary remarks. He thought the most severe critic of an author was the author himself. The discussion had missed many of the points that he had been quite prepared to hear criticised.

He agreed with almost every conclusion arrived at by Dr. Hatfield, but had to point out that the reagent was designed to detect areas in which phosphides in solid solution were concentrated in steel and iron, and not to isolate free phosphides in pig irons. When applied to pig irons containing mixtures of free carbides and phosphides both remained white, and copper did not deposit on either. On the other hand, when applied to very high silicon pig irons in which no free carbides existed, it was useful in showing the parts in which silicon was concentrated. He greatly appreciated the attempts Dr. Hatfield had made to find whether or not the reagent was useful in the examination of pig irons, and hoped he would continue his research in that direction.

Professor Le Chatelier had given them a valuable method for the etching of pig metals or metals containing free phosphides and carbides, by use of which the free phosphides were darkened, while the other parts, including the carbides, remained white. He believed the method would be of great value.

He agreed generally with the remarks of Dr. Rosenhain. It was certain that in pig iron, during and after the solidification process, silicon diffused from the parts richer in that element into portions containing less, and if the silicon was not excessive in grey iron, it became fairly equally distributed, but if excessive, it did not, and the variations could be detected by the use of the cupric reagents. He (Dr. Stead) had stated that in proportion as the phosphorus was increased in steels containing under 0·6 per cent. carbon, the white ghost lines became more and more pronounced, and it was quite possible that rolled steels, high in phosphorus with very pronounced zebra structure, might fail in use. He agreed with Dr. Rosenhain that lower magnification than those employed by Dr. Hatfield would have shown the structure better. Most of his (Dr. Stead's) illustrations were magnified only fifty diameters.

With regard to internal stresses set up in different critical ranges during cooling, having an influence on the final properties of the steel, he could say nothing. He doubted whether the effect would be appreciable.

Mr. Saniter had drawn attention to an omission in the recipe for making the new reagent. He (Dr. Stead) had not stated the proportion of water; he had, however, made the necessary correction in the paper. The salts were dissolved to saturation in water, and the alcohol, &c., were then added. If in larger amount, copper deposited over the whole surface.

He should have mentioned in his paper a method first described by Mr. Saniter which was very useful for separating the soft and purer parts from mixtures containing free phosphides, by simply crushing and sieving off the brittle and readily powdered phosphide. The purer portions became flattened into flakes and were left on the sieve. He thoroughly appreciated Mr. Saniter's remarks regarding the iron found in the brickwork of a Clarence mixer. It was possible the liquid iron was forced in by pressure, and that when solidifying, the pressure being continued, a portion of the eutectic was squeezed out of it, and that this passed into another part of the porous brick.

Mr. Saniter suggested that phosphide lines *plus* carbon might be worse than the same lines free from that element. The same thought had occurred to him, and that Nature was kind in removing the carbon from these, when the steel was slowly cooled, for by that process the tenacity of the ghost lines and the exterior metal were made more equal. As pointed out by Mr. Saniter, the origin of ghost lines was not only blow-hole segregation, but also inter-crystalline portions rich in phosphorus which were the last parts to freeze and which were trapped between the crystals. When Mr. Saniter saw the dendrites in steel, without using the cupric reagents, he (Dr. Stead) supposed he had first slightly etched the polished surface. If that were done, the dendrites could be seen, as he (Dr. Stead) had shown and illustrated in several of his previous papers.

He thoroughly appreciated Mr. Ralph Scott's question as to circumferential pressure. He had mentioned in the paper that circumferential pressure was produced, not only by contraction of the metal which first solidified near the walls of the hearth, but also by the gradual graphite formation in the cooling metal. The total expansion due to the formation of 1 per cent. of graphite was about 1·8 per cent. in volume. The metal as it cooled from the outside gradually changed from the white to grey condition, and as it expanded, in consequence of graphite formation, the circumferential pressure was in this way increased, and the centre part was necessarily under exceedingly high pressure. The cooling of huge masses was exceedingly slow. Two hundred or three hundred tons of metal buried in the ground and surrounded by earth and non-conducting substances would cool at a much slower rate than the metal in the largest ingot or casting. The conditions referred to by Mr. Scott differed materially from those in bears of blast-furnaces.

Professor McWilliam was quite right in thinking that the transverse direction of rolled phosphorettic steel was the one in which most danger was to be apprehended. The particular piece of "ghost-lined" steel shown in photograph No. 32 on the last plate of the paper was, however, very strong in the transverse section, as was proved by placing it on a 'V' block and striking it with great force; for the steel did not break along the lines. On that account he considered that some ghost lines, not highly saturated with phosphorus, were not actually dangerous. He quite understood the trouble Professor McWilliam had in judging whether or not to reject material exhibiting ghost lines; that was a problem which had to be left to the discretion of the intelligent and high-class inspector.

The carburisation of iron by carbonic oxide at temperatures well below the critical points, incidentally referred to in his paper, was a most interesting discovery, for which Mr. Byrom of Wigan was responsible. Mr. Byrom had promised to prepare a paper for reading at that meeting, but was unfortunately prevented. He (Dr. Stead) had been working in conjunction with him for some time, and they had found that pure iron could be completely converted into Fe_3C by exposing it to the action of blast-furnace gases rich in carbonic oxide, at a temperature under 600° C., and that the carbon did not pass by diffusion from the outside layers. The carbonic oxide entered into the interior of the mass and was decomposed, carbide of iron, Fe_3C and CO_2 gas being produced. He hoped Mr. Byrom would present his paper at the next meeting.

Professor Edwards had told him that he was preparing a short note upon the subject he had referred to in the discussion, and he was sorry he had not done so. He, however, was glad that he had described his results at that meeting. They showed to what an extraordinary extent phosphorus might become segregated in the presence of carbon, and that a steel containing 0·14 phosphorus yielded concentrations in the segregated part containing at least 10 per cent. phosphorus.

CORRESPONDENCE.

Dr. **Cecil H. Desch** (Glasgow) wrote that Dr. Stead's monograph was a remarkable and most valuable study of a complicated system. In regard to the diagram of thermal equilibrium, it might be pointed out that Saklatwalla's iron-phosphorus diagram, which was improbable in itself, had been superseded by later work. N. A. Konstantinoff[1] had re-determined the constitution of these alloys, and a diagram, completed from his data, was now subjoined (Fig. 2*a*). It would be seen that there was only a single maximum on the freezing-point curve, namely, that corresponding with the compound Fe_2P; whilst the more familiar phosphide, Fe_3P, decomposed below its melting-point into the higher phosphide and liquid. Two circumstances had misled Saklatwalla. The change taking place at about 1150° on cooling, being a reaction between two solid phases, resulted in the formation of a structure not unlike that of a eutectic. The presence of a eutectic implied that of a maximum nearer to the iron end of the system; hence the very improbable steeply falling branch DK. In the second place, the alloys were very liable to undercooling, and the crystallisation of Fe_3P was frequently suppressed, giving rise to the metastable freezing-point curve indicated in the diagram by dotted lines. When sufficiently undercooled the compound Fe_3P was formed with considerable development of heat, and this was no doubt the origin of the stepped "eutectic" line to the erroneous character of which Dr. Stead had called attention. The curves of the stable system had been determined by Konstantinoff by inoculating with the appropriate solid phase when taking each cooling curve.

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[1] *Zeitschrift für anorganische Chemie*, 1909, vol. lxvi. p. 209.

In Fig. 3*a* he (Dr. Desch) had represented some of the principal facts relating to the ternary system of iron, iron phosphide, and iron carbide, using the data given by Goerens,[1] together with those furnished by Dr. Stead. The lower figure gave the projection of the liquidus surface, made up of three portions, corresponding with the primary crystallisation of solid solution, phosphide, and carbide (cementite) respectively. For the sake of convenience, the carbon percentages had been plotted to twice the scale of the phosphorus percentages.

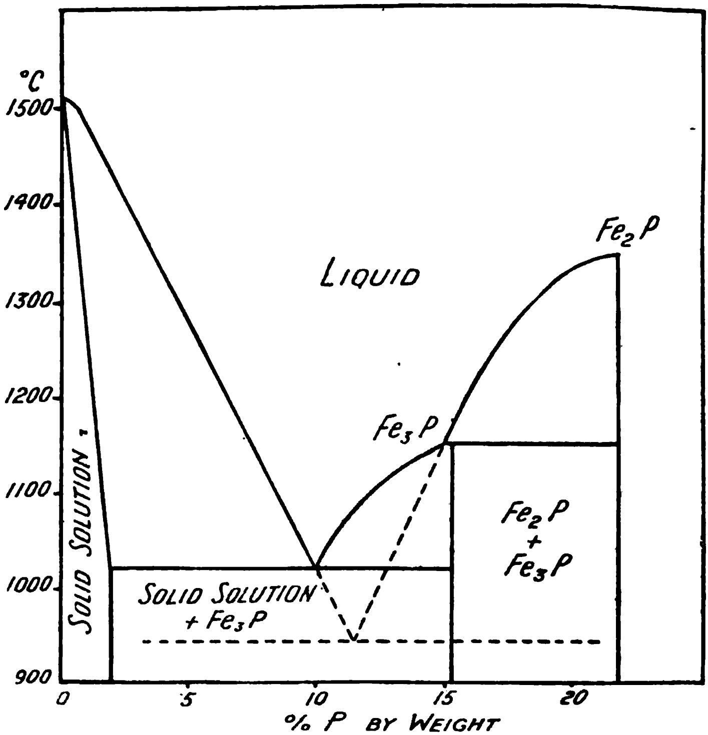

FIG. 2*a*.—Iron and Phosphorus. Metastable system indicated by dotted line.

The surfaces were separated by three binary eutectic curves, intersecting at a ternary eutectic point.

The upper figure represented the space model in elevation. Only the principal features had been inserted, in order to avoid confusion. The features of the two binary systems, iron-iron phosphide and iron-cementite, would be readily recognised. The third binary system, cementite-phosphide, was known to be of the simple eutectiferous form. The formation of graphite had not been taken into account.

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[1] *Metallurgie*, 1909, vol. vi, pp. 531, 537.

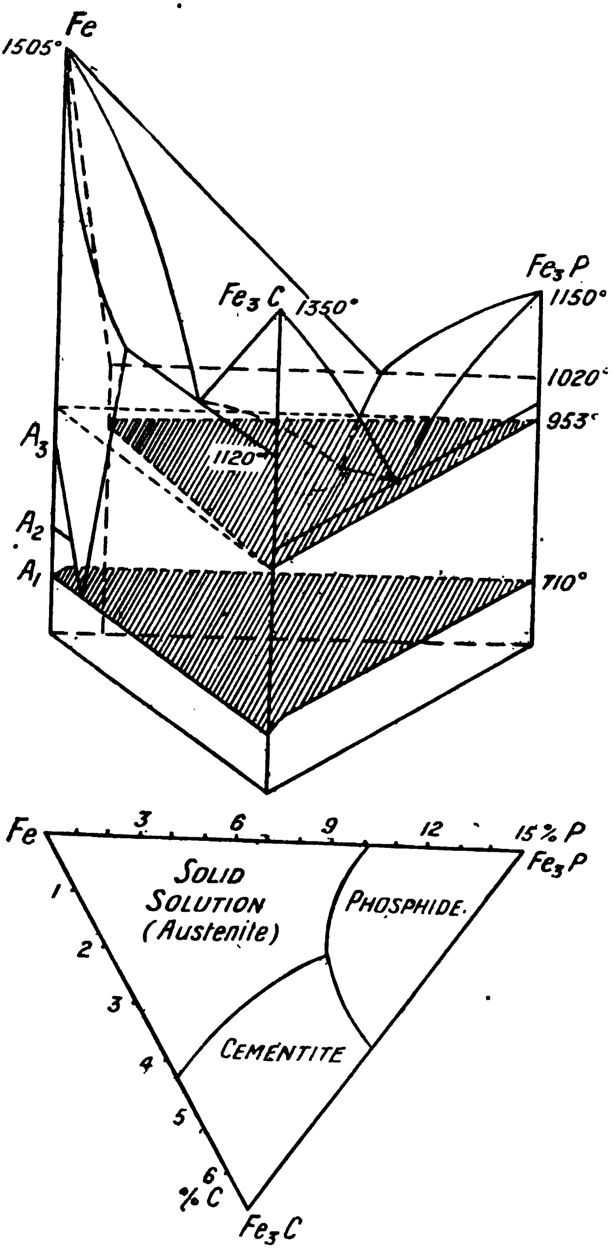
Fe
1505°
Fe₃C
1350°
Fe₃P
1150°
1020°
953°
1120°
A₃
A₂
A₁
710°
Fe
3
6
9
12
15 % P
Fe₃P
1
2
3
4
5
6
% C
Fe₃C
SOLID SOLUTION (Austenite)
PHOSPHIDE.
CEMENTITE

FIG. 3a.

The ternary eutectic surface at 953° had been shaded for greater clearness. It did not extend across the whole section of the prism, as on account of the solubility of both phosphide and carbide in iron at high temperatures there were two ranges of alloys which solidified without forming any ternary eutectic. Only the three binary eutectic curves had been inserted in the diagram, the corresponding surfaces being omitted for the sake of clearness. There did not appear to be sufficient data to complete the diagram below 953°. It was evident from Dr. Stead's observations that carbide and phosphide were mutually exclusive, so that the range of composition of the solid solutions must narrow rapidly with falling temperature, but prolonged annealing would be necessary in order to determine the actual limits, owing to the slowness of diffusion and consequent difficulty of attaining equilibrium. A1 was raised, and for alloys containing more than a small quantity of phosphorus was constant at 710°. This was indicated in the diagram by the lower shaded surface, leaving the boundary curve between the inclined and horizontal portions indeterminate. A complete representation of the available data would require a series of diagrams in the form of successive sections through the space model.

He (Dr. Desch) had had occasion to make tests of the cupric etching reagents in his laboratory. Difficulties were met with at first, the etching being patchy and uncertain, but this proved to be due to traces of grease on the surface of the specimens. When proper precautions were taken to ensure cleanliness the etchings became regular, and the structures observed were completely reproducible. Most success was obtained with Rosenhain and Haughton's reagent, using alcohol instead of water as the solvent, but the use of each reagent demanded a certain apprenticeship, and the beautiful photographs in the present paper were sufficient evidence of the value of Dr. Stead's reagent.

Professor H. **Le Chatelier**, Member of Council, wrote that he had had, since the meeting, an opportunity of making experiments with Dr. Stead's new reagent, and thought it advisable to draw attention to a difficulty that he (Professor Le Chatelier) had met with in using it.

The results described by Dr. Stead could only be reproduced on condition that a reagent of strictly accurately ascertained composition was used, and the details given by Dr. Stead were not sufficiently ample to make success certain. He had not indicated the proportion of water employed to dissolve the chlorides of copper and of magnesium, although, as a matter of fact, the success of the operation depended entirely on the right proportion of water. He (Professor Le Chatelier) had obtained the best results with a solution prepared as follows:—

Absolute methyl-alcohol	100 cubic centimetres.
Cupric chloride ($CuCl_2,2H_2O$)	1 gramme.
Magnesium chloride ($MgCl_2,6H_2O$)	4 grammes.
Concentrated hydrochloric acid	2 cubic centimetres.
Water	18 cubic centimetres.

With a reagent of this composition the white patches in phosphoric sheets were readily distinguished (Fig. 4*a*). With a smaller quantity of water hardly any copper was deposited, whereas with more water the copper became deposited uniformly over the whole section.

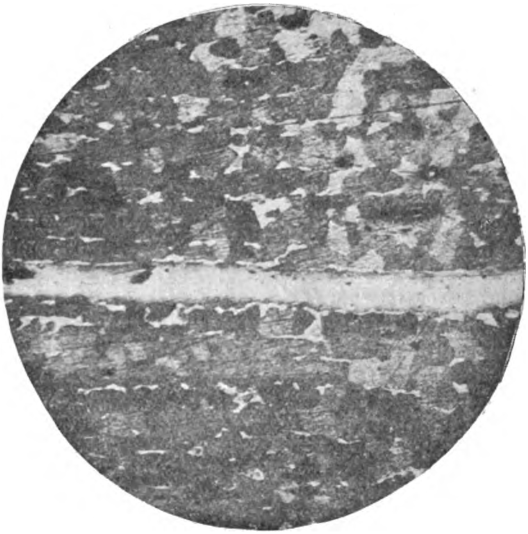

FIG. 4*a*.—Phosphorettic Iron Sheet etched with Dr. Stead's reagent.

Dr. **Stead** wrote in reply to Professor H. Lé Chatelier's communication, that he regretted that in his paper, when describing the method of making his new reagent, the words " D saturation " were left out. The salts are dissolved in hot water to saturation, and the alcohol, &c., added to the aqueous solution.

The actual volume of water was nearer 10 per cent. than the 17 per cent. proposed by Professor Le Chatelier. It is probable that in using the reagent he immersed the specimens in the liquid, and if that were so 17 per cent. would be necessary.

He (Dr. Stead) had found the same results as Professor Le Chatelier on having too little or too much water present in the reagent.

In his paper he (Dr. Stead) had stated that the specimens must not be immersed, but drops of the liquid should be dropped on the surface of the polished metals. The advantage of doing that was to secure delicacy in the result. When a drop of his solution spread itself over the surface, no action took place for a second or two, but as the alcohol evaporated, copper began to deposit on the purer parts; in other words, the reagent gradually adjusted itself to requirements.

Theoretically several solutions, with varying percentages of water, might be used with advantage, if the specimens were immersed in the liquid. One contained the least water, being applied to specimens in which the variations in phosphorus were slight, as in Swedish bar iron; the other to metals containing more variable parts.

A reagent containing 17 per cent. water would deposit copper over the whole surface of Swedish iron, if immersed in the liquid.

If the reagent were made and used as described in his (Dr. Stead's) paper, the results would always be satisfactory. The reagent of Dr. Rosenhain gave almost the same results if made more dilute by the addition of alcohol.

Professor Le Chatelier's suggestion to etch specimens with the aid of some electric current was one that should be accepted as valuable. It would be remembered that Osmond developed the structure in metals in that way.

In answer to the remarks of Dr. Desch, he complimented that gentleman for adding a valuable supplement to his (Dr. Stead's) work, and thanked him for having referred to the important work of Konstantinoff. He doubted, however, the statement that Fe_3P decomposed below its melting point into the higher phosphide and liquid. He had, in fact, obtained an alloy solidified from a liquid containing about 15·5 per cent. phosphorus, which was practically homogeneous, and also an alloy containing more phosphorus from which he had separated crystals of both Fe_8P and Fe_2P. The conflicting views showed how complicated was the constitution of the iron-phosphorus alloys.

He welcomed the diagrams introduced by Dr. Desch, and was sure they would be considered by all as a valuable addition. He also noted that Dr. Desch had modified the composition of Dr. Rosenhain's reagent and obtained superior results.

ON THE NATURE OF THE A2 TRANSFORMATION IN IRON.

BY KÔTARÔ HONDA (IMPERIAL TOHOKU UNIVERSITY, JAPAN).

SECTION I.—INTRODUCTION.

THE question of the A2 or magnetic transformation of iron has recently attracted the attention of metallurgists and physicists alike. Within the last few years several important theories and experimental results on this subject have been published and discussed by eminent scientists.[1] In the present paper, a critical study of the recent investigations on the said transformation is given; and the view of the present author that the A2 transformation is not an allotropic change in the ordinary sense of the word, but a change taking place in the molecules themselves, is subsequently explained at length. An allotropic transformation is a change in a substance from one phase to another at a definite temperature, that is, a change in the molecular configuration; but the A2 transformation is probably due to a change in molecular form associated with the rise of temperature, gradually beginning at a low temperature, proceeding with increasing speed as the temperature rises, and ending at the critical point.

That the A3 transformation is an allotropic change is generally recognised, and is confirmed by the recent experiments of C. K. Burgess, T. T. Crowe, C. Benedicks, and the present author.

As is well known, the A1 transformation is a eutectic transformation which is observable in steel, especially in carbon steels; it is characterised by a considerable evolution of heat, and is on this account usually termed "recalescence."

If a substance undergoes a change, whether it be a change of state, an allotropic or an intermolecular change, that change is generally accompanied by a change in the physical properties of the substance. Hence by observing the change in the latter, we may conclude that not only has a change taken place in the substance, but we can also observe in some cases the progress of the change itself with regard to the time or the temperature. Among the properties available for such investigations may be enumerated heat evolution, crystallographic change, magnetic properties, thermal expansion, electric resistance, thermo-electric properties, elasticity, &c.

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[1] A good collection of literature on the subject is to be found in the papers "Critical Ranges A2 and A3 of Pure Iron," by C. K. Burgess and T. T. Crowe, and "Behaviour of Ferro-magnetic Mixtures and Dilatation of Pure Iron," by C. Benedicks.

It is generally difficult to say which of these properties is the most effective in ascertaining that a change has taken place in a substance. In some cases one property will be preferable to another; in other cases it may fail to be available at all. In many cases, however, the thermal analysis is a convenient method of detecting a change, although this is sometimes associated with considerable difficulty, especially if it involves a change with a minute evolution of heat, or if the heat evolves within some temperature range, as in the case of the A2 transformation. In the latter case the method is not very suitable for tracing the progress of the change; because when the heat is once evolved, the substance takes time to cool to its initial temperature, so that from the cooling or heating curves we cannot well decide the time or the temperature at which the heat evolution ceases. Hence for investigating the progress of a change, the other properties, such as magnetism, thermal expansion, electric resistance, &c., are much to be preferred, if the methods of measuring them be sufficiently sensitive; because these properties are not accompanied by any time-lag as in the case of heat phenomena. Notwithstanding these considerations, previous workers have mostly used the method of thermal analysis to investigate the transformation.

For this investigation experiments with different kinds of steel are also important. Experiments with nickel and cobalt are for the same reason no less important than the above metals; because these elements belong to the same group in the periodic system, and have properties very similar to iron. It seems to the author that they have not hitherto attracted the attention they deserve in discussions of the A2 transformation.

The various views expressed by different investigators with regard to the A2 transformation are as follows:—

1. The transformation is an allotropic change (α to β) occurring at a definite temperature, or at least within a small range of temperature;
2. β-iron is not an independent phase, but a solid solution of α- and γ-iron;
3. The transformation is not an allotropic change, but an intermolecular change, taking place in α phase within a considerable range of temperature.

Since the publication of the valuable work of Osmond, it has been with more or less certainty assumed that α and β are two different states of iron. Although this view raises several difficulties in explaining the facts actually observed, G. Tammann,[1] G. K. Burgess,[2] Howe,[3] A. Sauveur,[4] Rosenhain,[5] and others support it. The supposition that the A2 transformation is not an allotropic change was first expressed by Le Chatelier,[6] and then by P. Weiss.[7] This view has recently been supported by Hadfield,[8] C. Benedicks,[9] and the present author.[10] Benedicks asserts that β-iron has no independent existence, and is merely a solid solution of magnetic α-iron with non-magnetic γ-iron. The present author likewise does not consider the A2 or magnetic transformation to be an allotropic change, but considers it to be an intermolecular change taking place within the α phase. In cooling, the transformation begins at the critical temperature, proceeds with the fall of temperature, at first rapidly and then becoming slower, and extends below the critical point to a considerable interval of temperature. In heating, the reverse transformation takes place, terminating at the same critical point.

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[1] G. Tammann, *Zeitschrift für physikalische Chemie*, 1908, vol. lxv. p. 79.

[2] Burgess and Crowe, *Scientific Papers of Bureau of Standards*, 1914, No. 213.

[3] Howe, *Transactions of the American Institute of Mining Engineers*, 1913, vol. xlvi. p. 1099.

[4] Sauveur, *Journal of the Iron and Steel Institute*, 1913, No. II. p. 171.

[5] Rosenhain and Humfrey, *Proceedings of the Royal Society*, London, 1909, vol. lxxxiii. p. 200.

[6] *Review de Métallographie*, 1904, vol. i. p. 213.

[7] *Archives des Sciences* (4), 1909, vol. xxvii. p. 1.

[8] *Transactions of the American Institute of Mining Engineers*, 1914, vol. xlvii. p. 513.

[9] *Journal of the Iron and Steel Institute*, 1912, No. II. p. 242; 1914, No. I. p. 407.

[10] *Science Reports*, Sendai, 1913, vol. ii. p. 69.

In order to criticise the different theories, it will be necessary to state here the experimental results of the different phenomena associated with the transformation. In what follows there will be given the results of the most recent experiments, and the different theories will be discussed in the light of these results.

SECTION 2.—HEAT ASSOCIATED WITH A2 TRANSFORMATION.

On June 6, 1913, the present author communicated to the Tôkyô Physico-Mathematical Society the results[1] of a series of experiments with pure iron from Kahlbaum, and different kinds of steel from F. Krupp, which determine on the one hand the heat associated with the A1, A2, A3 transformations, and on the other hand their magnetisation at high temperatures. For the method of experiments, reference should be made to the original report. The curves in Fig. 1 refer to the pure iron; the abscissæ are always the temperature θ of the specimen, and the ordinates of curves a and b are the deflection q (in centimetres) of the galvanometer for the differential thermocouple (curve a for cooling and b for heating); q is a quantity proportional to the heat evolved or absorbed during the transformations. The ordinates of curves a' and b' are taken proportional to $\frac{dq}{d\theta}$ according to Burgess and Crowe. In the cooling curves (a, a'), two marked maxima are observed; the first corresponds with the A3 transformation, which occurs principally at a definite temperature of 915° C., the gradient $\frac{dq}{d\theta}$ here becoming infinity. The second maximum corresponds with the A2 transformation, which, as will be shown, begins with the magnetic transformation. The evolution of heat does not occur at a definite temperature, but in a certain range, which is not less than 100°. In the heating curves (b, b') there are also two maxima; it is to be noticed that the absorption of heat on heating begins with a temperature of about 730° C., and that it ends at about the same temperature as in the cooling (compare curves a' and b'). The A3 transformation here takes place principally at a definite temperature of 935° C., the gradient $\frac{dq}{d\theta}$ becoming infinitely great. This temperature coincides closely with that determined magnetically.[1] Thus the A3 transformation takes place at a temperature higher by 20° than that in cooling. It is important to observe that the discontinuity on heating or cooling takes place respectively at about 10° lower or higher temperature than the one at which the curve q–e attains a minimum or a maximum.

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[1] *Science Reports*, Sendai, 1913, vol. ii. p. 69.

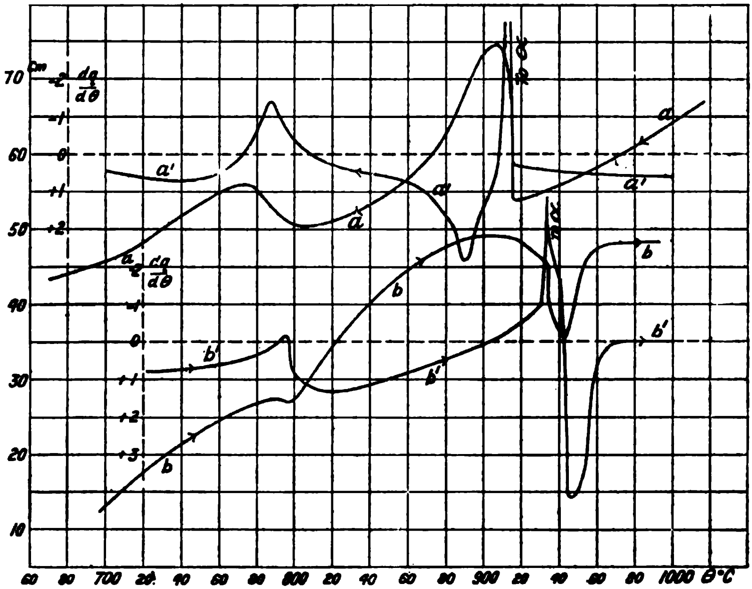

FIG. 1.—Pure Iron. (K. Honda.)

On September 22, 1913, G. K. Burgess and T. T. Crowe[2] published a valuable paper on the same subject, in which the numerous results of experiments with several specimens of pure iron were described. One set of their heating and cooling curves is reproduced in Fig. 2 for the sake of comparison. The courses of the corresponding curves in Figs. 1 and 2 are seen to correspond with each other. The heat evolution or absorption at A3 point is not, however, so sharply defined in Fig. 2 as in Fig. 1. The general results of their experiments is in close agreement with the author's result above referred to, the difference consisting in the values of the temperature of transformations. They found that in every pure iron there exist two marked maxima in the curves $q-\theta$ and $\frac{dq}{d\theta}-\theta$, which correspond with the two transformations A2 and A3. The evolution of heat in the A2 transformation is also not abrupt (see Fig. 2, *a*, *b*, for example), showing that the range of temperature is considerable. In their curves $\frac{dq}{d\theta}-\theta$ in heating the same fact can be noted, for the value of $\frac{dq}{d\theta}$ under the critical temperature is always greater than that above this temperature, and this shows that the heat absorption begins

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[1] P. Curie, *Œuvres*, 1908, p. 232; P. Weiss and G. Foëx, *Archives des Sciences*, 1911, Nos. 1, 2, vol. xxxi. pp. 5, 89; K. Honda and H. Takagi, *Science Reports*, Sendai, 1913, vol. i. p. 229.

[2] Burgess and Crowe, *loc. cit.*

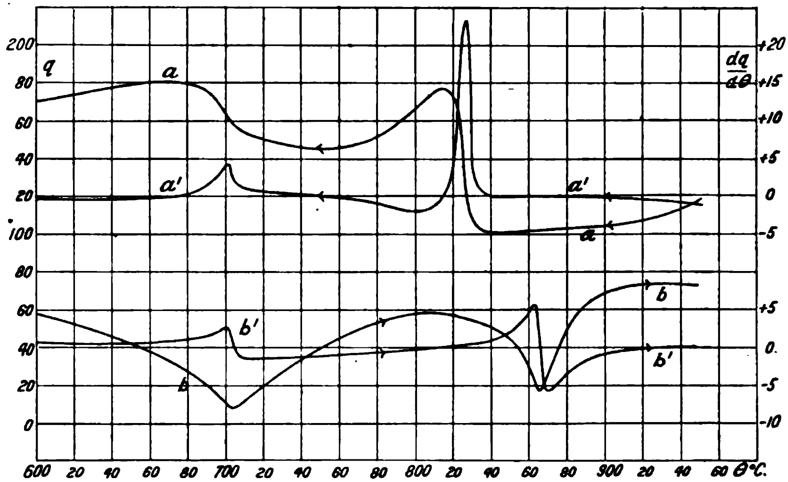

FIG. 2.—Pure Iron, F3. (Burgess and Crowe.)

with a temperature far below the critical point. From the above results the following conclusions may be drawn: The A3 transformation takes place principally at a definite temperature; on heating, this temperature is about 10° C. to 30° C. higher than that on cooling. The transformation is therefore reasonably considered as an allotropic change. On the other hand, the heat evolution or absorption corresponding with the A2 transformation takes place in a wide range of temperature, at least within a range over 100° C., although its greater part is evolved or absorbed within 30° C. to 40° C. As will be shown hereafter, the range probably extends to a still lower temperature. The A2 transformation is therefore probably not an allotropic change. If the transformation covers so wide a range it cannot be properly said to be a one-phase allotropy, if Benedicks' nomenclature be employed. It is equally incorrect to speak of the temperature, at which $\frac{dq}{d\theta}$ is the maximum, as the critical point or range, as do Burgess and Crowe. In the author's opinion, it is far better and clearer to speak of the temperature at which the heat evolution begins on cooling, or the heat absorption ends on heating, as the critical point; thereby meaning that at this point the transformation begins or ends, but that it does not take place at that temperature, and that the temperature is the one at which the ferro-magnetic property of iron changes to the para-magnetic.

According to Benedicks, the A2 transformation is a change associated with the A3 transformation; he was once of opinion that the evolution of heat at A2 point was due to the residual effect of the A3 transformation brought down by the impurities of iron. Pure iron could not therefore show any A2 transformation; but the result of the experiments above referred to shows clearly a distinct evolution or absorption of heat in the transformation in question. His view is not therefore plausible. That the A2 transformation has no relation to the A3 transformation is also supported by the fact that nickel and cobalt, which have no transformation corresponding to A3, show likewise the heat phenomenon corresponding to A2. This phenomenon was first experimentally proved by the present author,[1] and afterwards by Baikow.[2]

In Fig. 3, two curves, *a*, *b*, from the author's paper are reproduced; the course of the curves is quite similar to that of iron. As will be shown hereafter, the heat phenomena in iron, nickel, and cobalt take place exactly in the range of the magnetic transformations, showing that these two phenomena are merely a different aspect of one and the same change taking place in the substances.

P. Weiss, G. Beck,[3] and more recently Meuten,[4] measured the specific heat of iron, steel, and nickel at different high temperatures. As, however, these metals evolve heat by cooling in the A2 transformation, what they deduced is not really a change of specific heat with temperature, but merely the quantity of heat evolved during the transformation as measured calorimetrically. The method is not so delicate as that of thermal analysis, and therefore not well adapted for the examination of the heat evolution at different stages of the transformation. One point worthy of notice is the fact that by the calorimetric method the absolute value of the heat evolved during the said transformation can be determined.

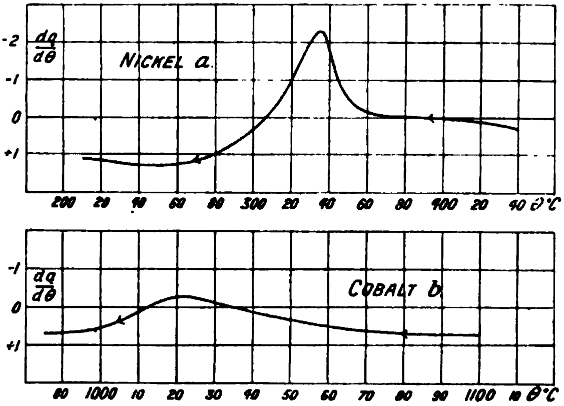

FIG. 3, *a*, *b*.

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[1] K. Honda, *Science Reports*, 1913, vol. i. p. 69.

[2] Baikow, *International Journal of Metallography*, 1914, vol. vi. p. 115.

[3] *Journal de Physique*, 1908, vol. vii. p. 249.

[4] *Ferrum*, 1912, vol. i. p. 1.

Lastly, some of the curves $\frac{dq}{d\theta}-\theta$ in cooling obtained by the present author for twelve kinds of steel containing different amounts of carbon will be given in Fig. 4, *a* to *l*. Two kinds of steel containing the smallest amounts of carbon, that is, 0·14 per cent. carbon and 0·18 per cent. carbon, have three marked maxima corresponding to A3, A2, A1; the last is the eutectic point, the value $\frac{dq}{d\theta}$ here becoming infinitely great. It is striking to observe that with an addition of so small an amount of carbon as 0·14 per cent. the heat evolution in A3

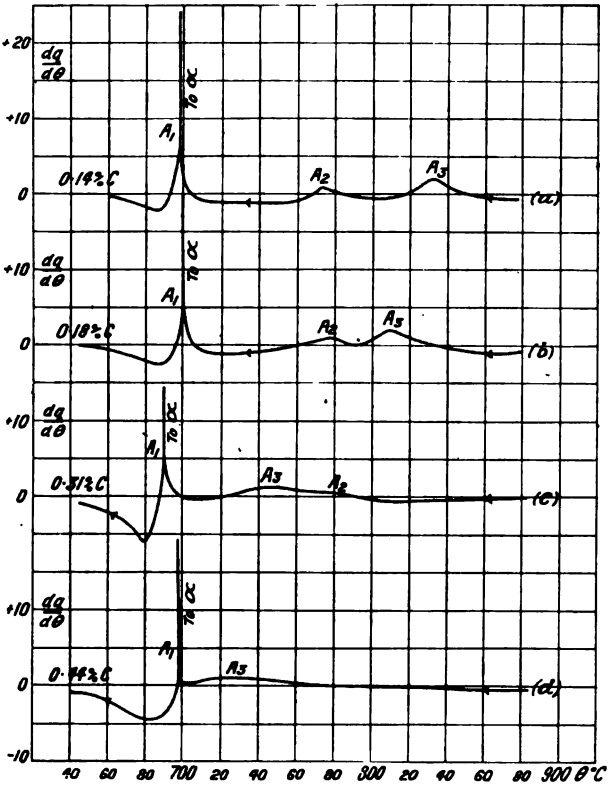

FIG. 4, *a*, *b*, *c*, *d*.—Steels. (K. Honda.)

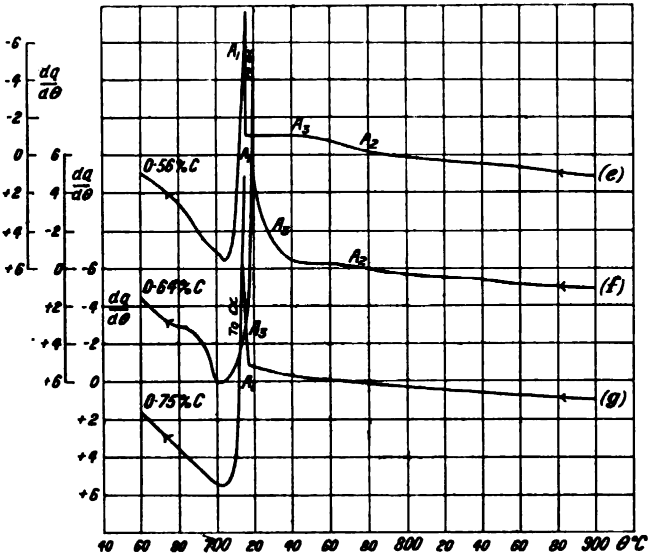

FIG. 4, *e*, *f*, *g*.—Steels. (K. Honda.)

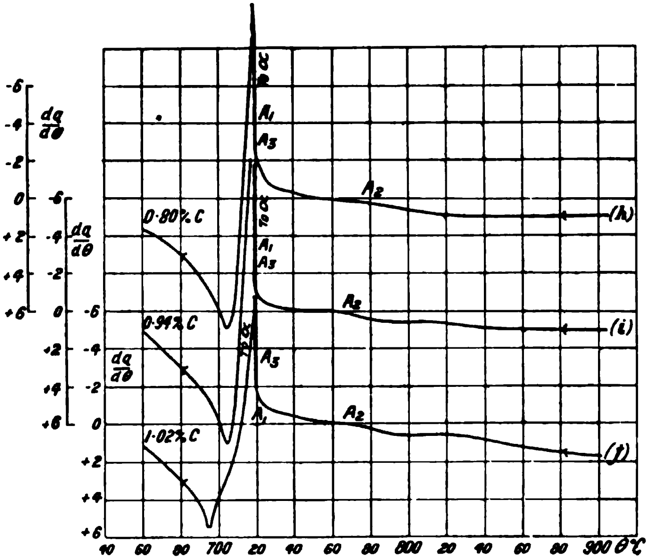

FIG. 4, *h*, *i*, *j*.—Steels.

point becomes very small and gradual as compared with pure iron, and that the same point is depressed by more than 60° C. With a further increase of carbon, the heat evolution in the same transformation becomes more and more inconspicuous, and its temperature becomes continuously lower, until it coincides with the eutectic point by about 0·8 per cent. carbon.

The heat evolution in the A2 transformation becomes like-

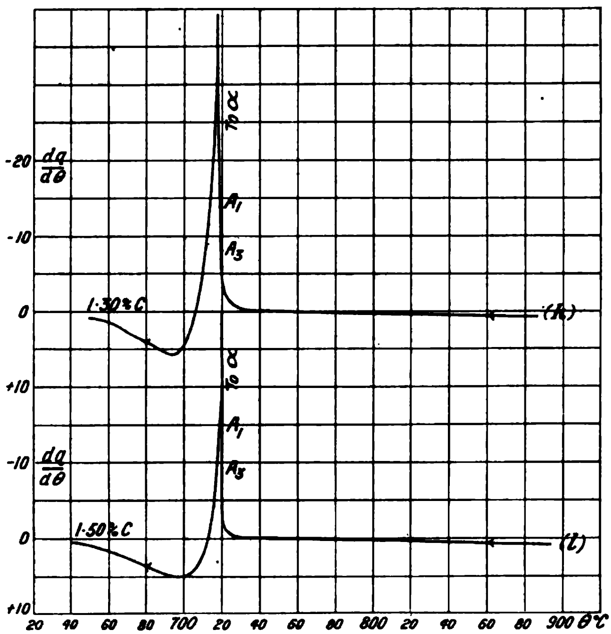

FIG. 4, *k*, *l*.—Steels.

wise less conspicuous with the increase of carbon content; with steels containing a higher percentage of carbon than 0·75 the existence of the transformation can scarcely be traced on the curves. From the curves it seems probable that the beginning of the transformation temperature remains fairly constant in spite of the increase of carbon content, decreasing a little with the content of carbon. That this inference is correct will be seen from the magnetic experiments to be described later on. The eutectic point remains fairly constant, and increases but little with the rise of carbon. The deflection q of the galvanometer at the eutectic point increases nearly proportionally with the carbon content, or with the quantity of eutecticum, until it reaches a maximum at about 0·8 per cent. carbon, and then slightly diminishes. This fact is to be expected. The well-known phenomena of recalescence is a consequence of the large amount of heat evolved in the eutectic separation. The commonly prevailing view that in steel containing a higher percentage of carbon than 0·9, A2 and A3 coincide with A1 is not correct, if we understand by the A2 point the temperature at which the heat evolution or the ferro-magnetism begins on cooling or ends on heating; because, as has been said above, A2 point remains nearly constant for all steels of different carbon contents. As will be shown hereafter, the magnetisation of steel of high carbon content undergoes on heating or cooling a greater part of its change at the eutectic transformation; hence if the A2 point be defined as a temperature corresponding with the maximum rate of change of magnetisation, the prevailing view is not incorrect, but only improperly expressed.

The above results for iron and steel may be summarised as follows: In pure iron the A3 transformation takes place mostly at a definite temperature. In steel the transformation proceeds in an interval of temperature. The point at which the transformation in question begins on cooling decreases rapidly with the increase of carbon content; the interval will perhaps extend in its lower limit to the eutectic point. This point remains fairly constant for steels of different carbon content. The A2 point, which according to the author's definition is the beginning of the transformation on cooling or its end on heating, decreases slightly with the increase of carbon content. The normal equilibrium diagram of the iron-carbon system takes therefore a form as indicated in the annexed figure, the points corresponding with the A2 transformation being included in a dotted line; thereby meaning that this line does not express

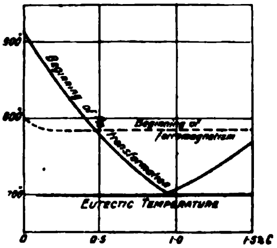

FIG. A.

any change of phase occurring at the temperature, and that it indicates the beginning of an intermolecular transformation in iron, the discussion of which forms the main object of the present paper.

SECTION 3.—MAGNETISATION AT HIGH TEMPERATURES.

By some metallurgists it is frequently stated that the magnetisation of ferro-magnetic metals undergoes an abrupt change at their critical points or ranges, but this is generally not the case. In fact the course of the magnetisation-temperature curves I–θ changes greatly with the strength of the magnetising field. Although this is a well-known fact, yet some examples from my experiment[1] will not be superfluous.

The experiment was performed with pure iron and nickel, and also with different kinds of steel from F. Krupp. The form of the specimens was a cylinder 10 centimetres long and 5 millimetres in diameter. In Fig. 5, *a*, *b*, the curves I–θ by heating for iron and nickel are given; the ordinates represent the intensity of magnetisation in absolute units and the abscissæ the temperature. The interval magnetising field (external field demagnetising force at 250° C.) is annexed to each curve. In Fig. 6 a curve obtained by J. Hopkinson for iron in a very weak field is reproduced, to show how the course of the curves in weak fields differs from that in strong fields. In a very weak field the magnetisation of iron and nickel (also that of other ferro-magnetic substances) increases with temperature, at first slowly and then very rapidly, and after reaching a sharp maximum it falls very rapidly at the critical temperature. With the increase of magnetising field this effect of increasing magnetisation becomes continually less. In a field of several gauss the magnetisation remains constant up to the critical range, and then falls very rapidly. With further increase of field the magnetisation begins gradually to decrease from a temperature which is lower as the field is stronger. In a field of some hundreds the magnetisation begins gradually to decrease from room temperature. In all cases the effect of temperature on magnetisation is two-fold, and the observed change of magnetisation is the sum of these two effects. The first effect is specially conspicuous in weak fields, and becomes continuously less as the field is increased. The effect is similar to the well-known mechanical tapping on magnetisation,[1] and increases the magnetisation, the thermal agitation here playing the part of mechanical shocks. The second is a reversible effect, and always acts in diminishing magnetisation. By incessant thermal impacts the molecular

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[1] K. Honda, *Science Reports*, vol. i. *loc. cit.*

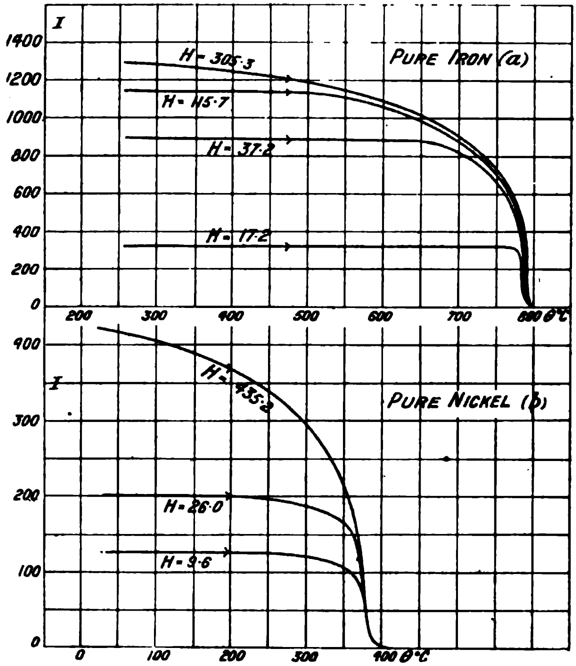

FIG. 5, *a*, *b*. (K. Honda.)

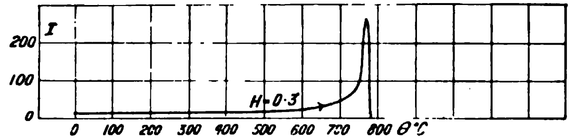

FIG. 6.—Iron. (J. Hopkinson.)

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[1] Ewing, "Magnetic Induction," new edition, p. 112.

magnets execute rotational vibrations about their mean orientations, and the mean magnetic effect is diminished by the vibration; it is therefore easy to see that the decrease of magnetisation increases with the amplitude of rotational vibration—that is, with the rise of temperature. In very strong fields the first effect no longer obtains, and there exists chiefly the second reversible effect of temperature. In the present paper, the first, less important effect is left out of consideration, and the second only will be discussed.

Strictly speaking, a cylinder is not uniformly magnetised by a uniform field, so that the above results refer to the mean intensity of magnetisation. Although the author's measurement of magnetisation at different temperatures was made under constant external fields, yet, owing to the demagnetising force, the effective field was not quite constant in cases where the magnetisation varied considerably with temperature. The general course of these curves will not, however, be much affected if they be referred to the constant effective field; for, in the author's case, the demagnetising factor was fairly small, amounting only to 0·072.

To obtain strictly correct curves of $I-\theta$ it is necessary to make experiments with an ovoid placed in a uniform magnetic field; the specimen will then be uniformly magnetised. The curves of magnetisation at different constant temperatures are taken up to a desired strength of magnetising field. These curves are then reduced to those of the magnetisation-effective field, by taking the demagnetising force into account. We obtain a sufficient number of such curves, each corresponding to a definite high temperature; by cutting these curves by a constant effective field the curves $I-\theta$ under constant effective fields are obtained. In Fig. 7, *a*, *b*, *c*, *d*, some of the results of such investigations by Mr. S. Shimizu and the present author[1] are given. The curves for iron and nickel are similar to those of strong fields above referred to; those of reversible nickel-steel have also a similar course as that of nickel.

R. Ruer and K. Kaneko[2] made some magnetic measurements with nickel-cobalt and iron-cobalt alloys, and specially remarked that their magnetisation appears on cooling or disappears on heating very suddenly at their critical temperatures. But this sudden change of magnetisation is by no means an indication that the magnetic transformation is an allotropic change. For, as they used very short specimens, the demagnetising force must be very large, and therefore the effective field very small; the magnetisation will change then very abruptly at the original point, but if the magnetising field be much stronger the change of magnetisation will take place in a much wider range of temperature.

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[1] *Journal of the College of Science*, 1905, vol. xx. Art. 6.

[2] *Ferrum*, 1913, vol. x. p. 257.

C. Benedicks[1] recently communicated to the Iron and Steel Institute a paper, in the first part of which he described the result of his experiment with ferro-magnetic mixture, and tried to explain by his result the thermo-magnetic behaviour of ferro-magnetic substances in the A2 range. This explanation does not appear to the author to be correct. For, as already remarked by M'Cance[2] and accepted by Benedicks himself, the deviation of the curves for magnetisation-concentration from a straight line is evidently due to the demagnetising action of the ferro-magnetic particles in the mixture, so that if a sufficiently strong field, for example, 1000 gauss, be applied, a fairly linear relation between the magnetisation and the concentration would be obtained. A similar remark

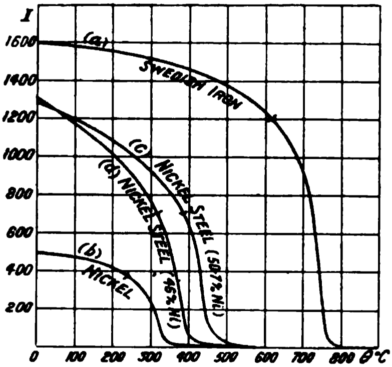

FIG. 7, *a*, *b*, *c*, *d*. H=400. (Honda and Shimizu.)

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[1] *Journal of the Iron and Steel Institute*, 1914, No. I. p. 407.

[2] *Ibid.*, p. 449.

has been already made by the present author in the case of ferro-magnetic alloy of the system manganese-antimony.[1] On the other hand, previous experiments on the magnetisation of iron at different high temperatures under constant strong fields (>several hundred gauss), especially that of P. Curie (Fig. 8, *a*), show that the course of the curves does not materially change with the strength of the magnetising field. If his view be correct, there should be a linear relation between the magnetisation and the concentration in a range from some 900° C. to 750° C., provided the field be sufficiently strong. This is, however, not actually the case. Hence, here again, it is impossible to agree with Benedicks' theory of solid solution of α- and γ-iron.

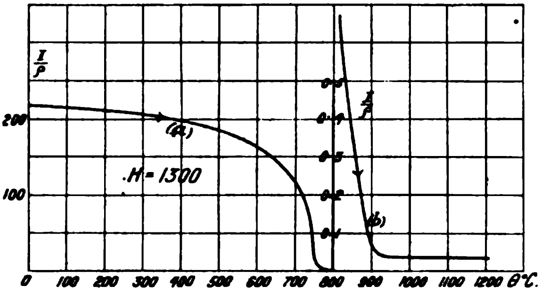

FIG. 8.—Pure Iron. (P. Curie.)

From the result above given for iron and nickel the following conclusions may be drawn: In strong fields, when the irreversible thermal effect is negligible, the magnetisation begins to diminish from the lowest temperature, the change per degree of temperature increasing at first gradually, but becoming always greater as the critical temperature is approached. If the change of magnetisation indicates that intermolecular change is taking place in the substance, which at the same time manifests itself as the evolution or absorption of heat, then the two quantities q and I must vary parallel to each other. Strictly speaking, the heat should therefore begin to be absorbed from the lowest temperature in the case of heating, though its amount is negligibly small, except in the

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[1] *Annalen der Physik*, 1910, vol. xxxii. p. 1005.

A2 range. The fact, as explained in the last paragraph, seems to stand in favour of the above view.

The magnetisation of steel at different high temperatures likewise deserves special attention. In Fig. 9, *a*, *b*, *c*, *d*, some of the results of my experiments[1] are given. From curve *a* we see that in a field of 6·2 gauss, the magnetisation of the steel with 0·18 per cent. carbon remains constant up to a temperature of 770° and then falls very rapidly. With the increase of the magnetising field, the magnetisation begins to decrease from a lower temperature, and above a field of 300 gauss it gradually decreases from the ordinary temperature, its rate of change becoming steadily greater as the critical point is approached. Similar remarks hold good for other steels (Fig. 9, *b*, *c*, *d*). It is interesting to remark that

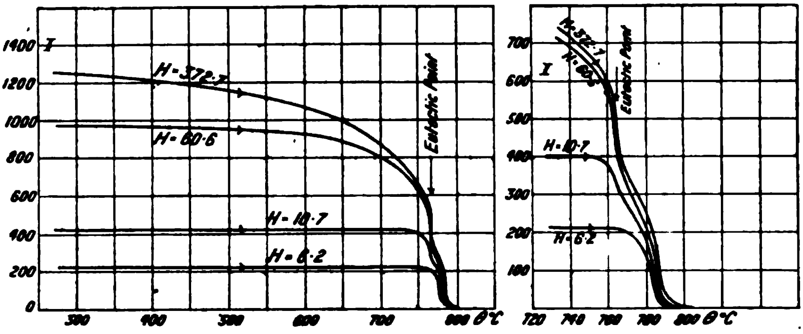

FIG. 9, *a*.—Steel, 0·18 per cent. Carbon.

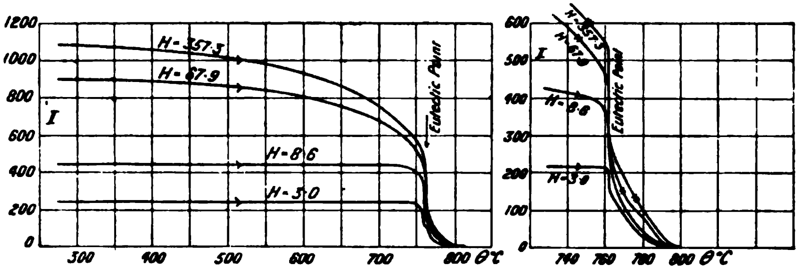

FIG. 9, *b*.—Steel, 0·44 per cent. Carbon.

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[1] K. Honda, *loc. cit.*; K. Honda and H. Takagi, *Science Reports*, 1912, vol. i. p. 207; 1913, vol. ii. p. 203.

the magnetisation changes discontinuously at the eutectic or A1 point, and the amount of this abrupt change increases with the quantity of the eutecticum. In steel of high carbon content, the greater part of the magnetisation disappears by heating at the eutectic point. The course of the whole curve is as if the ordinary continuous change of magnetisation observable in pure iron were broken at the eutectic point. The magnetisation by cooling also shows a similar change; the difference is that the eutectic change of magnetisation by cooling is 30° C. to 60° C. lower than that by heating.

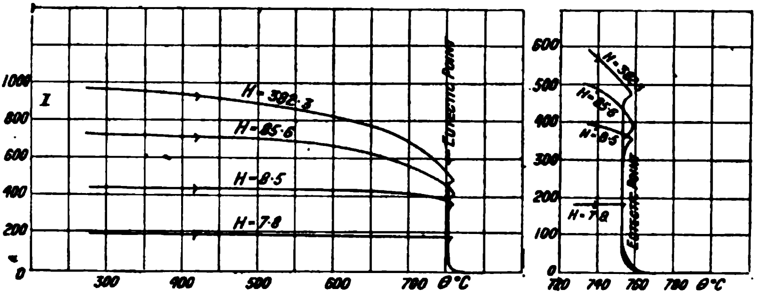

FIG. 9, *c*.—Steel, 0·80 per cent. Carbon.

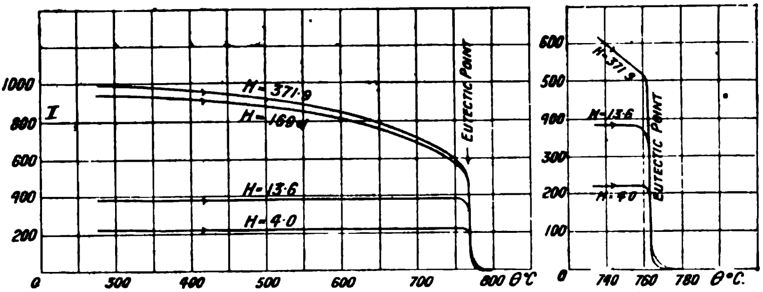

FIG. 9, *d*.—Steel, 1·30 per cent. Carbon.

The above interesting fact, that the magnetisation changes discontinuously at the eutectic point, is in close agreement with the following general fact:[1] If a ferro-magnetic element forms a mixed crystal with a non-magnetic element, the critical point is markedly lowered, and the range of diminution of magnetisation with the rise of temperature becomes considerable. In steel, above the eutectic point, the magnetic ferrite forms a mixed crystal with cementite, which is non-magnetic above 250° C.; hence if, by heating, the eutectic mixture changes to a mixed crystal, the magnetisation will decrease abruptly, the amount of change increasing with the quantity of eutecticum.

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[1] G. Tammann, *Physikalische Chemie*, vol. lxv., *loc. cit.*; K. Honda, *Annalen der Physik*, vol. xxxii., *loc. cit.*

In a paper[1] entitled "The Thermo-magnetic Properties of Iron and Steels," Mr. H. Takagi and the author showed by a special experiment that the magnetisation of steel after its discontinuous diminution at the eutectic point can be traced up to 800° C. to 780° C. for heating, as well as for cooling. As the eutectic points of different kinds of steel are 30° C. to 60° C. higher in heating than those in cooling, the change of magnetisation above the eutectic points is comparatively faster in heating than in cooling. In Fig. 10, *a, b, c, d,* some of our results are reproduced. The fact that for steels of higher carbon content a magnetism, after an abrupt diminution at the eutectic point, can be traced to a higher temperature (780° C.) deserves special attention; for this leads to a magnetic γ-iron, which is contrary to the prevailing view among metallurgists. If the A2 transformation be considered as a gradual internal change taking place in the molecules of iron, whether iron be in α or γ state, the above fact is readily explained.

In steel there is observed also another transformation between 150° C. and 220° C. which is revealed by the diminution of magnetisation in heating or by its increase in cooling. The percentage of this change of magnetisation increases with the carbon content of steel. As was stated by S. W. J. Smith,[2] the change of magnetisation is probably due to the magnetic transformation of cementite. This view is also supported by a recent experiment by the present author, which will be published shortly.

In conclusion, this paragraph remarks on the change of magnetisation in the intermediate stage between the ferromagnetic and para-magnetic state may be made. In Fig. 5,

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[1] K. Honda and H. Takagi, *loc. cit.*, vol. ii.

[2] *Proceedings of the Physiological Society*, London, 1912, vol. xxv. p. 77.

a, b, it is observed that in heating, the magnetisation of iron and nickel becomes zero at about 790° C. and 395° C. respectively; this does not, however, mean that the magnetisation here completely vanishes, but only indicates that the magnetisation is too small to be measured magnetometrically. To see how this minute residual magnetism changes at higher temperatures, a specially sensitive arrangement must be used. Such accurate experiments were at first made by P. Curie,[1]

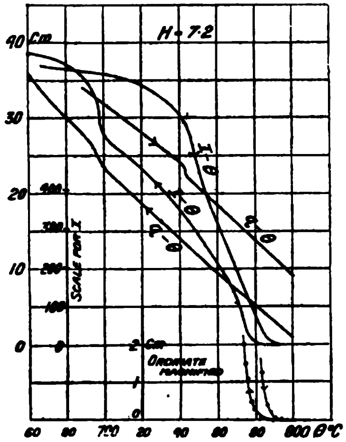

FIG. 10, *a*.—Steel, 0·18 per cent. Carbon.

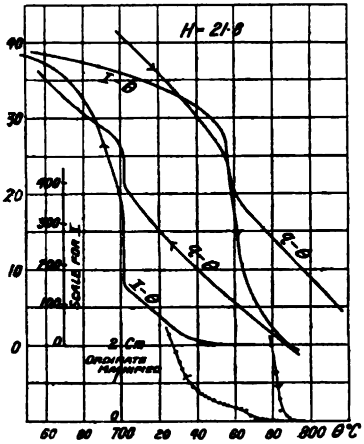

FIG. 10, *b*.—Steel, 0·44 per cent. Carbon.

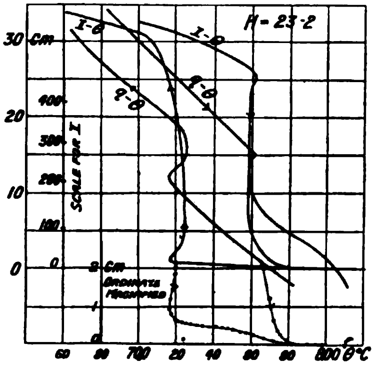

FIG. 10, *c*.—Steel, 0·80 per cent. Carbon.

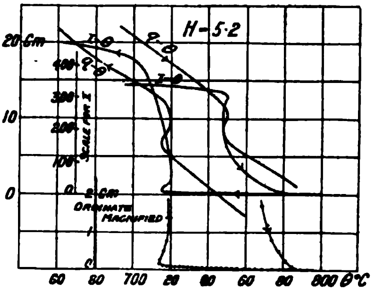

FIG. 10, *d*.—Steel, 1·30 per cent. Carbon.

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[1] *Œuvres de Curie*, 1908, p. 232.

and subsequently by P. Weiss, G. Foëx,[1] O. Block,[2] H. Takagi, and the author.[3] In Fig. 11, *a*, *b*, *c*, the results of Mr. Takagi and the author are given. If Fig. 5, *b*, be compared with Fig. 11, *a*, it will be observed, in the first place, that the scale of ordinates of the latter curve is about 800 times greater than that of the former; and secondly, that though the magnetisation magnetometrically vanishes at about 395°, its absolute magnitude has yet a definite value and steadily diminishes with further increase of temperature, the rate of

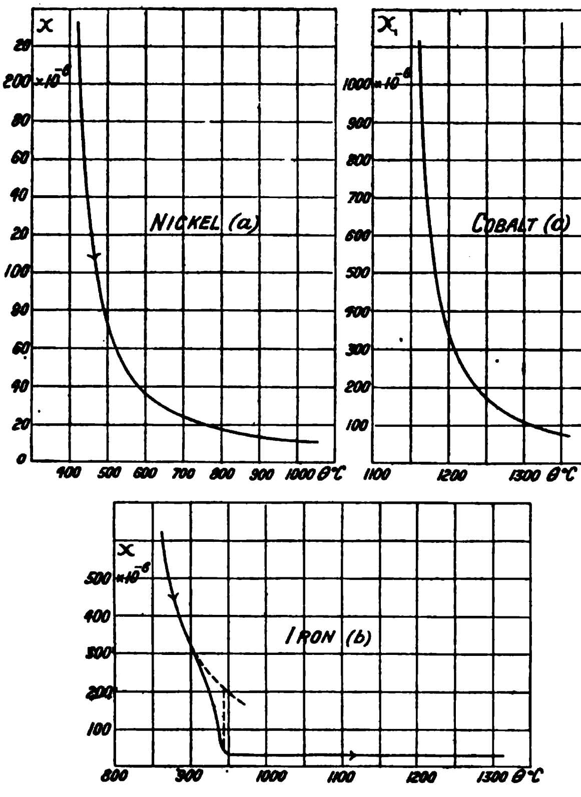

FIG. 11, *a*, *b*, *c*.—X = Specific Susceptibility. (K. Honda and H. Takagi.)

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[1] *Archives des Sciences Physiques et Naturelles*, 1911, Nos. 1, 2, vol. xxxi. pp. 5, 89.

[2] *Ibid.*, 1912, No. 4, vol. xxxiii. p. 293.

[3] *Science Reports*, Sendai, 1913, vol. ii. p. 229.

diminution, however, becoming steadily less. The change from the ferro-magnetic state to the para-magnetic is therefore quite continuous. Magnetometrically measured the critical temperature is then fairly well defined; but, strictly speaking, no such specially defined point exists in the curve I–θ. Similar remarks hold good for cobalt (Fig. 11, *c*).

In pure iron, one important difference is noticed in consequence of the A3 transformation (935° C. in the heating curve). If this transformation were absent, the course of the curve (Fig. 11, *b*, and Fig. 8, *b*) would be the same as in nickel and cobalt (this course has been indicated by a dotted line in Fig. 11, *b*); but the A3 transformation changes the property of iron so much as to depress the susceptibility χ to a considerable amount. The curve χ–θ shows, therefore, an inflexion at the transformation point. The same anomaly was also observed by P. Weiss. He tried by his theory to find the number of magnetons in iron, by applying Curie's law to his curve χ–θ; but in consequence of the anomaly, it was not possible to express this curve by Curie's law; so he divided the curve into two portions, $\beta 1$ and $\beta 2$, in each of which the law with different constants will apply. But the above considerations show that $\beta 2$ is merely a transition stage from β to γ, if the name "β-iron" be preserved, and therefore Weiss' conception is not correct.

According to the author's view above explained, the normal curve I–θ for pure iron must therefore have a form as given in the annexed figure.

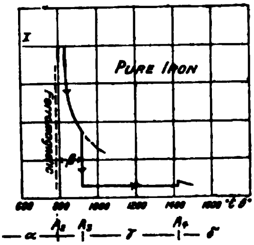

FIG. B.

In pure iron there are three modifications, α, γ, δ, the last of which was first observed by P. Curie,[1] then P. Weiss, G. Foëx,[2] W. Gontermann,[3] and more recently fully investigated by R. Ruer and K. Kaneko.[4]

Below A3 point, iron is in a state α; in cooling, an intermolecular change begins to take place at about 790°, which is also accompanied by an evolution of heat, by a development of ferro-magnetism, and by the change of other physical properties. Between the A3 and A4 points iron exists in feebly para-magnetic state α, and above the A4 point it is in a state δ, a little more magnetic than γ. The so-called β-iron is the name given to that state of iron which lies between the A2 and A3 points.

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[1] *Œuvres de Curie, loc. cit.*

[2] *Archives des Sciences Physiques et Naturelles*, vol. xxxi. *loc. cit.*

[3] *Zeitschrift für anorganische Chemie*, 1908, vol. lix. p. 378.

[4] *Ferrum*, vol. x. *loc. cit.*

SECTION 4.—DOES THE A2 TRANSFORMATION DEPEND UPON EXTERNAL CONDITIONS?

With regard to the nature of the magnetic transformation, it is very important to investigate whether the range of transformation depends on the rate of heating or cooling. The author carried out a series of such experiments[1] with Swedish iron and nickel. As the effect of the strength of the magnetising field on the form of I–θ curves is already well known, it suffices to investigate the above question for a certain magnetising field. The specimens used were 2·5 centimetres long and 1 centimetre thick in a form of a cylinder, and the external field was 107 gauss, but owing to the large demagnetising force of the specimen, the effective field did not certainly exceed 10 gauss, so that the apparent transformation occurred in a small range of temperatures, and this was a great convenience in investigating such effect.

The results of the experiments are given in the following tables and in Fig. 12, *a*, *b*:—

Nickel. H = 106·4 gauss.

Interval . .	m. s. 1 10	m. s. 2 40	m. s. 4 10	m. s. 4 40	m. s. 6 10	m. s. 12 20	m. s. 15 40	m. 33	m. 79
Transform. interval	22°	23°	22°	20°	21°	19°	19°	18°	19°

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[1] *Science Reports*, vol. ii. *loc. cit.*

Swedish Iron. H = 106·4 gauss.

Interval	s. 55	m. s. 2 0	m. s. 3 50	m. s. 7 20	m. s. 14 40	m. 23	m. 46
Transform. interval	12°	12°	12°	12°	13°	10°	11°

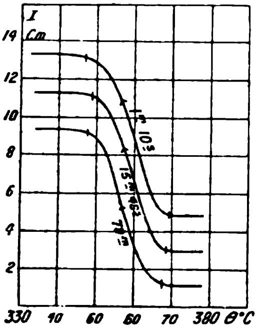

FIG. 12, *a*.—Nickel.
(K. Honda.)

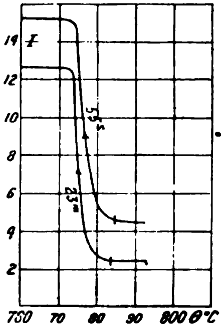

FIG. 12, *b*.—Swedish Iron.
(K. Honda.)

From the above tables it is seen that although the interval of the magnetic transformation appears slightly to decrease with the interval of cooling, yet it remains fairly constant for all cooling intervals. The small initial decrease may well be explained by the fact that in such rapid cooling the temperature of the specimen may not be quite uniform throughout the specimen, and so a slight elongation of the interval is observed. The following conclusion may therefore be arrived at:—In a definite magnetising field, the magnetic transformation takes place in a certain definite interval independent of the rate of cooling or heating. In fact, the magnetisation is a definite function of temperatures. This result does not stand in favour of the allotropic theory, but it is in good agreement with my view above explained.

The next important question is whether the heat evolution or absorption depends on external conditions to which the specimen is exposed. The author investigated this question for different magnetising fields;[1] some results are given in

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[1] *Science Reports*, vol. ii. *loc. cit.*

Fig. 13, *a*, *b*. His experiments showed that for external magnetising fields of 0, 107, 160, and 1290 gauss, the heat evolution in iron and nickel during the cooling does not appreciably change. This again indicates that the transformation is probably not a change of molecular configuration, although it is a change which has a profound relation to the molecules themselves.

Lastly, one more experiment made by the present author may be mentioned. This related to the question whether the magnetic change and the heat phenomena were really different aspects of one and the same transformation taking place in the substance. This question was solved by making simultaneous observations of the magnetisation and the heat evolution in the critical range of pure iron and nickel. Some results are given in Fig. 14, *a*, *b*, *c*, *d*. Here the ordinate represents on the one hand the quantity proportional to the magnetisation, and on the other hand the deflection q of the galvanometer, while the abscissa is always the temperature.

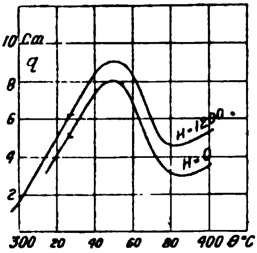

FIG. 13, *a*.—Nickel.

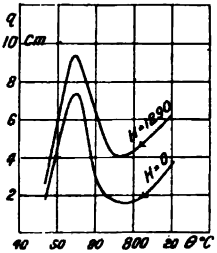

FIG. 13, *b*.—Pure Iron.

In iron and nickel the temperature of the beginning of the magnetic transformation in cooling and the temperature of its ending in heating coincide well with the corresponding temperatures of heat evolution and absorption respectively. That is, the critical temperature as determined magnetically agrees with that as determined thermally. It will be likewise seen that in heating, the heat absorption begins at a much lower temperature than the magnetic transformation; and that in cooling, the heat evolution ends at a much lower temperature than the latter transformation. This divergency is, however, apparent, and has no important bearing; for, as has already been shown, the beginning of the magnetic transformation by heating or its ending by cooling depends on the strength of the magnetic field. It was a drawback to his experiment that it was made in an external field of only 107 gauss—that is, in a weak internal field, less than 10 gauss. With a strong internal field of several hundreds, the correlation between the change of magnetisation and the heat evolution would have been much more clearly brought out.

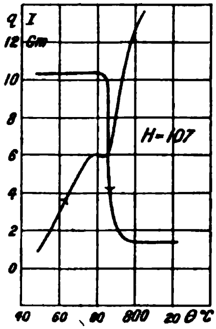

FIG. 14, *a*.—Swedish Iron. (K. Honda.)

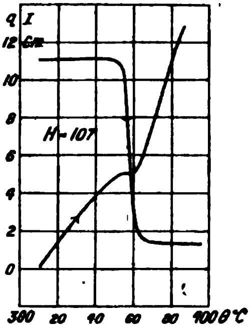

FIG. 14, *c*.—Nickel. (K. Honda.)

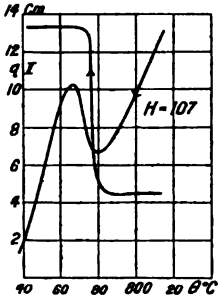

FIG. 14, *b*.—Swedish Iron. (K. Honda.)

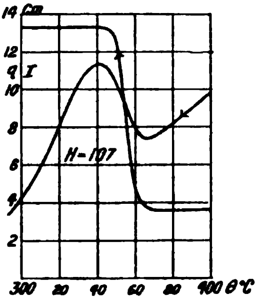

FIG. 14, *d*.—Nickel.

SECTION 5.—ELECTRIC RESISTANCE AT HIGH TEMPERATURES.

The change of electric resistance of iron, steel, nickel, and iron alloys was first investigated by H. Le Chatelier;[1] the result was that at the critical ranges the curves of resistance-temperature R–θ show all a kick more or less definite. Similar results were afterwards obtained by J. Hopkinson,[2] K. Morris,[3] E. P. Harrison,[4] A. R. Meyer,[5] B. Cabrera and J. Torroja.[6] Quite recently G. K. Burgess and I. N. Kellberg[7] made an accurate measurement with pure iron. From these results, there is no doubt that the curve R–θ possesses a more or less conspicuous kick near to 770°; but the question, to what temperature in the A2 range does the kick on the curve R–θ correspond, is not yet solved. Whether the critical point as determined magnetically coincides exactly with the kick, is a question to be solved by further experiments. For this purpose, Mr. Y. Ogura and the present author[8] made simultaneous observations of the magnetisation and the resistance on the same specimen. The specimens investigated were pure iron, nickel, and different kinds of steel from F. Krupp. For the method of experiments, reference will be made to the original.

Some results are found in Fig. 15, *a*, *b*, *c*, *d*. The ordinates represent on the one hand the resistance R, and on the other hand the deflection I of the magnetometer, which is proportional to the intensity of magnetisation, the origin of the ordinate I being arbitrarily taken. The abscissa always represents the temperature. In Fig. 15, *a*, *b*, it is seen that in iron and nickel the kicks *b* in the curves R–θ exactly coincide with the final temperature of the magnetic transformation—that is, with the critical temperature. Further, if the course of the two curves R–θ and I–θ be compared, the following conclusions may be drawn: If the ferro-magnetic property of the specimens be absent, the curves R–θ below the critical points should take the course *bc′*, as indicated by the dotted lines; but by the ferro-magnetic property of the metals the resistance is so far reduced that the curve R–θ actually takes the course *bc*. According to this consideration the change of the resistance with temperature is quite parallel to that of magnetisation. That above the critical temperature the curve R–θ is nearly straight, and its continuation cuts the axis of temperature near the absolute zero, is in good agreement with the general fact found in the case of pure non-magnetic metals. It seems to the author that all previous investigators have directed their attention merely to the kick in the curves R–θ,

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[1] *Comptes Rendus*, 1890, vol. cx. p. 283.

[2] *Transactions of the Royal Society* (A), 1889, vol. clxxx. p. 462.

[3] *Philosophical Magazine*, 1897, vol. xliv. p. 213.

[4] *Ibid.*, 1902, vol. iii. p. 191.

[5] *Inaug. Diss.*, Greifswald, 1911.

[6] *Anales de la Sociedad Española de Fisica y Quimica*, 1913, vol. xi. p. 1.

[7] *Journal of the Washington Academy of Sciences*, 1914, No. 15, vol. iv. p. 435. As to the date, this paper appeared after our paper described here.

[8] *Science Reports*, 1914, vol. ii. p. 113.

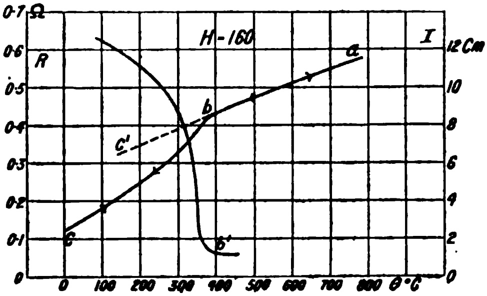

FIG. 15, *a*.—Nickel. (Honda and Ogura.)

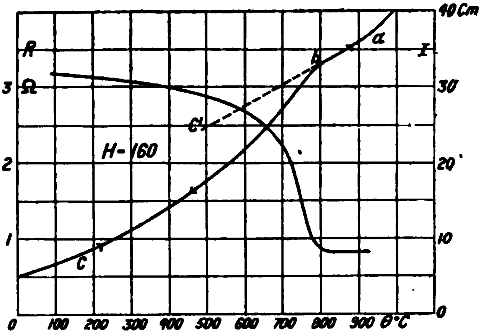

FIG. 15, *b*.—Pure Iron. (Honda and Ogura.)

and have not attached much importance to the curvature below the critical points; but, from the above, it is now clear that the abnormal course of the curves below the critical points is what is intimately related to the ferro-magnetic property of the metals, and that the important difference between the course of the curves before and after the kick is to be ascribed to the difference between the ferro-magnetic and para-magnetic properties of the specimens. Our result is thus in good agreement with the author's view regarding the A2 transformation already referred to.

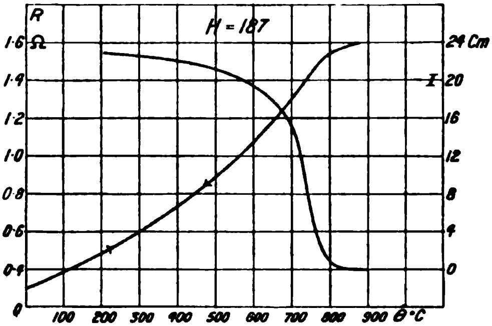

FIG. 15, *c*.—Steel, 0·44 per cent. Carbon. (Honda and Ogura.) H=187.

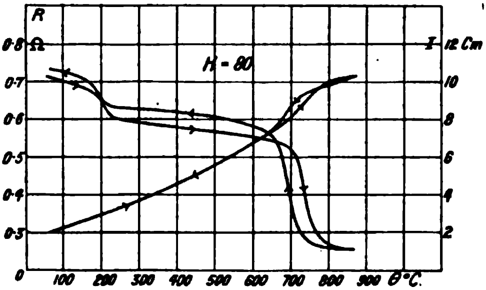

FIG. 15, *d*.—Steel, 1·30 per cent. Carbon. (Honda and Ogura.) H=80.

In pure iron a second point *a* is observed at 925° C., which is not so well defined as the first point. This corresponds to the A3 transformation. By a very accurate measurement Burgess and Kellberg[1] revealed a distinct abnormal change of resistance during this transformation. The measurement of resistance at high temperatures shows again an allotropic nature of the A3 transformation.

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[1] *Journal of the Washington Academy of Sciences, loc. cit.*

A remark deserves to be made about the results for different kinds of steel (Fig. 15, *c*, *d*). The general course of the curves R–θ is similar to that of iron, but the kick is not so marked as in iron. In iron, nickel, and steel of small carbon content the curves R–θ for cooling and heating are reversible. In steel of higher carbon content the curves I–θ show a considerable magnetic hysteresis at the eutectic point in heating and cooling; corresponding with this, there is also a considerable hysteresis in the curves R–θ at the eutectic point (Fig. 15, *d*). It is an interesting fact to observe that the electric resistance changes abruptly with the eutectic transformation, its amount increasing with the quantity of eutecticum.

SECTION 6.—THERMAL EXPANSIONS AT HIGH TEMPERATURES.

The anomalous change of length of steel at high temperatures, which was at first observed by Gorex, 1869, and then by Svedelius[1] and Le Chatelier,[2] is the elongation accompanying the eutectic transformation or at the point of recalescence. The experiments by G. Charpy and L. Grenet[3] and W. Broniewski[4] in iron and steel reveal another abrupt change of length at the A point. From the standpoint of thermal expansion, it may also be concluded that these two transformations are of the nature of a structural change. Quite recently C. Benedicks[5] made a very careful determination of the thermal expansion of pure iron. He used a differential method and an optical magnification to detect any minute abnormal expansion during the transformations. The accuracy of his appliances was far superior to that of previous investigators. Using palladium as the compensator, he was able to obtain a very abrupt change of length at A3 point; the discontinuous change of his cathetometer readings during the transformation even amounted to 150 divisions. Notwithstanding, at A2 range he could not find any abrupt change of length, and found only a slight bending down of the curve of dilatation-temperature e–θ. In Fig. 16 this portion of his curve is reproduced. If there be any discontinuity, it must be less by $\frac{3}{1000}$ than the discontinuity at A3 point; hence, as he asserts in his paper, it may safely be concluded that the question as to the ultimate discontinuity at A2 point is considered as settled. It is also easily seen that the slight gradual depression of the curve at A2 range is quite parallel to the gradual diminution of magnetisation with the rise of temperature.

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[1] *Philosophical Magazine*, 1898, vol. xlvi. p. 173.

[2] *Comptes Rendus*, 1899, vol. cxxix. p. 279.

[3] *Bulletin de la Société d'Encouragement*, 1903, pp. 464, 883.

[4] *Comptes Rendus*, 1913, vol. clvi. p. 699.

[5] *Journal of the Iron and Steel Institute*, 1914, No. I. p. 419.

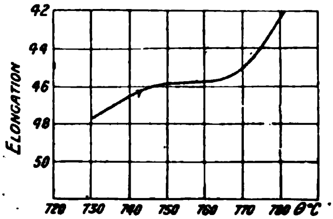

FIG. 16.—Differential dilatation, Fe-Pd. (Benedicks.)

In his discussion, G. K. Burgess expressed a doubt whether the distribution of the temperature along the specimen was sufficiently uniform. But as Benedicks had already remarked, he used a copper tube to improve the uniformity of the temperature, and this must doubtless be so effective in equalising the temperature along the specimen that there was not actually so much difference in temperatures as was supposed by Burgess. Admitting a small inequality of temperature along the specimen, the discontinuity at A point, if any, should be at least less than $\frac{1}{100}$ of the discontinuity at A3 point. Now the question whether the A2 transformation is an allotropic change or not depends not merely on the quality of discontinuity, but also on its quantity. Since the heat evolved or absorbed at A2 point is known to be about $\frac{1}{3}$ of the heat at A3 point, the discontinuity to be expected at A2 point should be of the same order of magnitude as that at A3 point, if it is to be considered as a proof of an allotropic change. This is, however, not the case, and therefore it must be considered that the result of the above experiments is contradictory to the allotropic theory, although the same result is in close agreement with the view of the present author.

SECTION 7.—MAGNETIC EXPANSIONS AT HIGH TEMPERATURES.

It is well known that ferro-magnetic substances undergo a change of dimensions on magnetisation. This phenomenon is generally known as the magnetostriction; its investigation at high temperatures also furnishes us with a knowledge as to the nature of the A2 transformation. About twelve years ago Mr. S. Shimizu and the present author[1] measured the magnetic expansion of iron, steel, nickel, and cobalt at different temperatures, ranging from −183° C. to 1000° C. For details of the apparatus and the method of experiment reference can be made to the original, but a brief description of it may not be out of place.

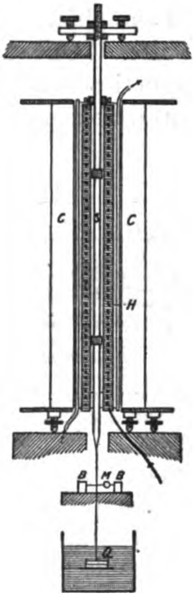

FIG. C.

The accompanying figure shows the front view of the apparatus. S is the rod to be tested, about 21 centimetres long and 1 centimetre thick. To each end a copper rod of the same diameter was joined by means of a copper screw and then brazed. This connected system hangs vertically from a stout support by means of a brass stand with three levelling screws. From the lower copper rod hangs copper wire 1 millimetre thick, which is stretched by a weight Q in a damping vessel. M is a reflecting mirror fixed to the rotating cylinder, the ends of which terminate in cones and fit lightly in the agate cups on the heads of screws in brass sockets BB. The vertical copper wire above mentioned with its slightly flattened surface touches the rotating cylinder with a suitable pressure. If the specimen elongates or contracts, the mirror rotates through a small angle, and the corresponding displacement of the image of a distant slit with a fine glass fibre is observed in a micrometer field. H is a heating coil, which is wound on a well insulated copper tube 40 centimetres long and 2·5 centimetres thick. C is the magnetising coil, provided with a water-jacketed arrangement to avoid its heating effect due to the heating coil.

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[1] *Journal of the College of Science*, 1903, vol. xix. Art. 10.

Some of the results of experiments are graphically shown in Fig. 17, *a*, *b*, *c*. Under a moderate field iron expands by magnetisation, but in a strong field it contracts. With the rise of temperature the elongation or the contraction algebraically increases, at first slowly and then somewhat rapidly. And after reaching a maximum at about 500° it rapidly diminishes, and vanishes at the critical point. A similar remark applies to cobalt. Tungsten steel always expands by magnetisation, and the change of expansion with the temperature is similar to iron. On the other hand, nickel always contracts by magnetisation. With the rise of temperature the amount of contraction gradually decreases till it vanishes at its critical temperature. Thus it is again seen here that the magnetic expansion diminishes quite gradually in approaching to their critical temperature, no discontinuous change being observed. This result also supports the view of the present author. In his paper on the dilatation of pure iron, C. Benedicks described an experiment on the magnetic expansion. From his observed result he concludes that the small bending down of the curve *e*–*θ* in the A2 range may be a consequence of the magnetostriction. In measuring the magnetic elongation he did not use any special magnetising coil; his heating coil served at the same time as a magnetising coil. Thus he broke the current in the heating coil and read the instantaneous contraction in length thereby caused. Such a method of measurement would give a much greater value than it actually does. In fact he found for pure iron a value

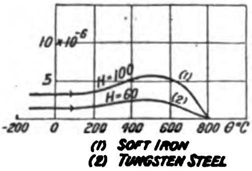

FIG. 17, *a*.—Iron and Steel. (Honda and Shimizu.)

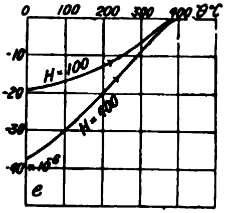

FIG. 17, *b*.—Nickel. (Honda and Shimizu.)

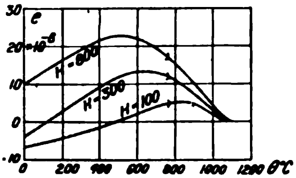

FIG. 17, *c*.—Cast Cobalt. (Honda and Shimizu.)

$e=12{\cdot}5\times10^{-6}$ in a field of 10 gauss and at 500°; while we found for soft iron a value $e=6\times10^{-8}$ in a field of 100 gauss and at 500°. Judged from the value for the magnetic elongation obtained by different workers, Benedicks' value in a field of only 10 gauss is too large. Since in weak fields the elongation is approximately proportional to the field strength, the true value could not possibly be greater than 10^{-6}. Hence the contraction of iron observed by Benedicks in the A2 range is too large to be explained by the magnetostriction, and it must be a real change associated with the said transformation. According to the author's view, such a gradual change of expansion, which corresponds to a gradual intermolecular change, is rather to be expected.

SECTION 8.—THERMO-ELECTRIC PROPERTY AT HIGH TEMPERATURES.

Tait[1] first observed that the thermo-electric property of iron and nickel changes abruptly in the A2 transformation. Harrison,[2] Belloc, and W. Broniewski[3] obtained similar results. More recently Broniewski[4] again investigated the same property for iron and steel of different contents of carbon; as the coupling wire he used copper. His valuable results are reproduced in Fig. 18. For pure iron and steel of 0·07 per cent. carbon in the curve of electromotive force temperature e–θ we observe A2 and A3 points, which are not well developed. In steel of higher carbon content we can only in curves e-θ find a kick corresponding to the A1 or eutectic transformation; the kick becomes more and more conspicuous with the increase of carbon content. A similar gradual change in the thermo-electricity, as in the critical range of iron, were also observed in the critical ranges of nickel and cobalt by C. Dannecker.[5]

For the study of the exact location of a transformation which extends to an interval of temperatures, the thermo-electricity is not well suited; because the different parts of wire to be tested is exposed to different high temperatures, so that there may result a pseudo-junction between the original and transformed parts of the same wire, and the thermo-electric current thereby resulting may be superposed on the effect to be studied. But if the transformation be abrupt, such as the A transformation, its location may well be detected by means of the thermo-electric current, as was actually the case with steel of high carbon content. At any rate, the results of thermo-electric experiments show that the A2 transformation does not take place abruptly, its beginning coinciding with the critical point.

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[1] Collected Papers, vol. i. p. 218.

[2] *Philosophical Magazine*, 1902, No. 6, vol. iii. p. 177.

[3] *Comptes Rendus*, 1913, vol. clvi. p. 669.

[4] *Ibid.*, p. 1983.

[5] *Annalen der Physik*, 1913, vol. xlii. p. 1504.

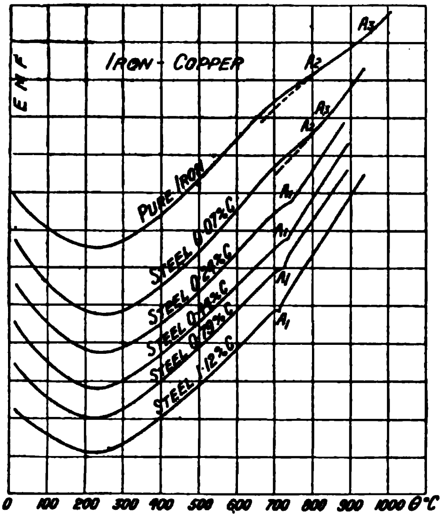

FIG. 18.—Thermo-electricity. (W. Broniewski.)

SECTION 9.—MECHANICAL PROPERTIES AND CRYSTALLOGRAPHIC STRUCTURE.

Besides the effects above enumerated, we have also the effect of temperature on the mechanical properties of metals. The only experiments which shed any light on the transformation points of iron and steel are those of Rosenhain and

Humfrey.[1] The result of their experiments with a steel of 0·1 per cent. carbon is given in Fig. 19. The points in the figure are the results of their experiments on the tensile strength; the full line T–θ was drawn by the present author through these points, and consequently in some respects differs from the original. The underlying curve is a cooling curve q–θ obtained by Rosenhain and Humfrey on same specimen. Here three maxima corresponding to A1, A2, A3 are noticed. The beginning of the A3 transformation nearly coincides with that of the bending down of the curve T–θ, and the discontinuous fall of the latter curve takes place at a little higher temperature than the point at which the curve q–θ attains a maximum. In the A2 region the curve has an anomalous course; the dotted branch is the supposed course, which according to the author's view should correspond to the curve in case, if there be no A transformation. The beginning of this transformation fairly coincides with that of the bending up of the curve T–θ. Thus here again there is other evidence that the A2 transformation does not take place abruptly, but on the contrary it goes on gradually. The discontinuity on the curve T–θ corresponding to the A1 transformation does not seem well developed.

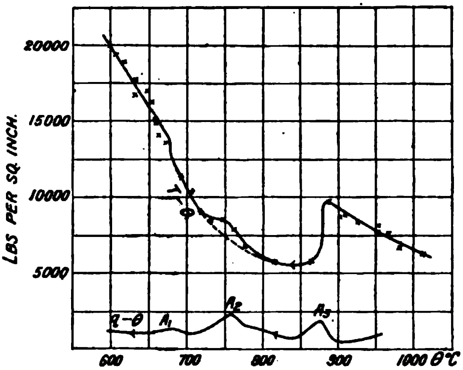

FIG. 19.—Tensile Strength. (Rosenhain and Humfrey.)

As to the crystalline structures of α- and β-irons, all experiments appear to show that there is no crystallographic difference between them.

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[1] *Journal of the Iron and Steel Institute*, 1913, No. I. p. 219.

All the results above considered, which were obtained from the investigations in many different directions, lead to the following conclusions: The A2 transformation is of a quite different nature compared to the A3 transformation, which is an allotropic change. The transformation is therefore not an allotropic one, but it is some intermolecular change, which takes place gradually in a phase and in a large interval of temperature. The interval of heat evolution will in a strict sense extend from the critical temperature to the lowest, the change of magnetisation with the temperature being considered as representing the rate of heat evolution at large. The similar magnetic change observable in nickel, cobalt, and other ferro-magnetics at their respective critical ranges are to be ascribed to the same intermolecular change as in iron. β-iron is the name given to that state of α-iron which lies between the critical and A3 points. From the standpoint of the phase doctrine, β-iron is to be rejected; but for the sake of convenience the name may well be preserved for the state of iron lying between the two points just referred to.

SECTION 10.—THEORY OF FERRO-MAGNETISM.

In the author's former paper,[1] he has tried to explain the different phenomena so far enumerated by the Weiss theory of ferro-magnetism. According to the latter, all minute crystals of iron and other ferro-magnetics which constitute these metals are each, in spite of their unmagnetised state, strongly magnetised in a direction of the so-called molecular field, thereby the thermal agitation diminishing their mean magnetic moment to a certain degree. But as the directions of these crystals are distributed in all directions, the metal does not show as a whole any magnetic polarity, If an external magnetic force acts on the metal, the molecular magnets tend to turn in the direction of the magnetic force against the molecular field. The molecular field is supposed to be proportional to the intensity of magnetisation, and to have an extraordinary large value amounting to several millions of gauss. The minute crystals are therefore magnetised to saturation at the temperature under consideration. With the rise of temperature, the magnetisation and therefore the molecular field diminish, at first slowly and then always faster, vanishing at the critical point. The heat evolved or absorbed during the A2 transformation is then explained by the magnetic energy. In fact, the experiment of P. Weiss and P. N. Beck[1] gives a result which agrees well with the theoretical result. Several other facts are also explained by the same theory.

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[1] *Science Reports*, 1913, vol. ii. p. 91.

The great difficulty of this theory consists in the extraordinary large value of the molecular field. In his recent paper, Weiss considers it to be of non-magnetic nature; how can it then be regarded as proportional to the intensity of magnetisation? It is a well-known fact that iron and nickel are magnetised nearly to saturation by the application of a field of several hundreds. If the molecular field be so large as several millions of gauss, how can this easy approach to saturation be explained? At any rate, it seems very difficult to explain by his theory of molecular field the fundamental phenomena regarding the induced magnetism.

Last year the present author published a theory of magnetism,[2] which is based, like that of Weiss, on the Langevin theory of para-magnetism; the theory explains the para-magnetic and ferro-magnetic substances and coincides in the latter case with the well-known theory of Ewing.[3] It also agrees well with the author's view regarding the A2 transformation above referred to. In what follows, the part of the author's theory which relates to the ferro-magnetic substance will be explained.

If a substance be magnetised by an external field, its molecular magnets tend to turn their axes in the direction of the field, but the mutual action of the molecules prevents them from turning freely round their own axes. Moreover, if the form of the molecules be not spherical, molecules will perform irregular rotatory vibrations, which are caused by the incessant impacts of thermal agitations, and consequently the mean magnetic effect in the direction of the field will be diminished. This weakening effect will increase with the rise of temperature. The effect of mutual action will be negligibly small in comparison with that of thermal impacts, unless the temperature is not very low. According to the theory of Langevin, a substance composed of such molecules is para-magnetic. If, however, the form of the molecules be a sphere, the molecular impact can produce a translation, but not any rotation, of the molecules. By the application of a small magnetic field, the molecules would place themselves with their axes in the direction of the field, unless the mutual action prevents their turning. The direction of the magnetic axis of each molecule is therefore determined by the external field and the mutual action. This case corresponds obviously to the well-known theory of Ewing for a ferro-magnetic substance, and therefore such substance is considered to be ferro-magnetic. The difference between the ferro-magnetic and para-magnetic substance is thus ascribed to that of the molecular form.

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[1] *Journal de Physique*, vol. vii. *loc. cit.*

[2] *Science Reports*, 1914, vol. iii. p. 171.

[3] "Magnetic Induction," new edition, p. 294.

If the mutual action be absent, a slight deviation of the form of molecules from the sphere will turn the ferro-magnetic substance to the para-magnetic; but as the mutual action is present, this is not the case. For, so long as the moment of resisting force due to mutual action be large in comparison with that due to the molecular impacts, the latter affects the distribution of the axes of the molecular magnet very little, and therefore the substance still behaves as a ferro-magnetic. In order, therefore, that a ferro-magnetic substance may turn to be a para-magnetic, a definite amount of deformation of the spherical molecules is necessary.

According to the above theory, the form of the molecules of a ferro-magnetic substance is nearly spherical, and the effect of thermal impacts in rotating the molecules is very small in comparison with the mutual action.

In a para-magnetic substance the molecule has an elongated or flattened form, and the effect of the mutual action is very small compared with the rotating effect of thermal impacts.

The theory of ferro-magnetism, though it is very simple, explains many observed facts. It was shown by Ewing that such a model of molecular magnets explains the fundamental properties of induced magnetism quite satisfactorily. It was also shown by Professor G. Tammann[1] that the compounds which are composed of a ferro-magnetic element and of a para-magnetic or a diamagnetic element are generally not ferro-magnetic. This is easily explained by the above theory; for a spherical ferro-magnetic molecule, when it combines with others, forms generally an elongated system, and therefore behaves as a para-magnetic substance. Two ferro-magnetic elements form a solid solution with each other, and consequently their alloys do not generally lose their ferro-magnetic property.[2] The case may also be conceivable where the molecules of non-magnetic elements may form a compound whose molecules are nearly spherical; these compounds are then ferro-magnetic. Heusler's alloys, some manganese and chromium compounds,[3] are to be considered as examples of such compounds. Non-magnetic nickel steel and Hadfield's manganese steel are also explained in the same way.

Thermo-magnetic property of the ferro-magnetics will be next considered. The transformation of a ferro-magnetic substance to a para-magnetic at high temperature is explained as a consequence of the gradual deformation of the spherical molecules with the rise of temperature. The heat evolved or absorbed during this transformation is considered to be the energy of deformation, and that imparted to the molecules to cause their rotatory vibrations. The irreversible effect of thermal agitations, which is only observable in weak fields, being left out of consideration, the reversible effect will be here discussed. At low temperatures the effect of thermal impacts is very small in comparison with that of mutual action. With the increase of temperature the molecules begin gradually to deform, and the effect of thermal impacts becomes more and more effective, till at last, with a certain amount of deformation of the molecules, it becomes very large in comparison with that of mutual action, and the substance becomes para-magnetic. It is also to be expected that in the last stage of deformation its slight increase may greatly effect an increase in the rotatory vibrations of the molecules in consequence of thermal impacts. Thus, as actually observed, the effect of temperature on magnetisation will at first be small, increasing steadily with temperature; in approaching to the critical point the decrease of magnetisation will be more and more rapid, till the substance becomes para-magnetic. If it be assumed that the heat absorbed during the said transformation consists mainly in the energy imparted to the molecules to increase their rotatory vibrations, the energy of deformation of the molecules being comparatively small, the course of the observed heating curve is readily explained. On the same supposition, it is evidently sufficient, but not necessary, to assume that the deformation of the molecules terminates at the critical temperature.

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[1] *Zeitschrift für Physikalische Chemie*, vol. lxv., *loc. cit.*

[2] It should be remarked that as iron, nickel, and cobalt are unlimitedly soluble to each other in solid solution, the compounds Fe_2Ni and Fe_2Co cannot much differ in character from the solid solution, and thus behave as a ferro-magnetic one.

[3] Ferro-magnetic compounds: Mn_3Sb_2, Mn_2Sb, Mn_2Sn, Mn_4Sn, MnP, Mn_5P_2, Mn_7N_2, Mn_5N_2, MnB, Cr_5O_9.

As the molecules of the ferro-magnetic substance undergo a continuous change in regard to their form and kinetic state with increasing temperature in a manner as explained in the above, it is to be expected that a corresponding change takes place generally in the properties of the substance, as actually observed. In passing, the following remark deserves notice: Since the molecules of iron or nickel execute in its ferro-magnetic state a much less rotatory vibration than in its para-magnetic state above its critical point, the electrons in the metal, in moving through it, must undergo in the former state a less resistance than in the latter. This agrees with the observed fact for the change of electric resistance of iron and nickel at high temperatures.

In conclusion, the following remarks on the nomenclature of the A2 transformation may not be out of place. According to the definition used in the present paper, the critical temperature is one at which the A2 or magnetic transformation begins by cooling or terminates by heating. Theoretically this temperature cannot be exactly defined, as the transition from the ferro-magnetic state to the para-magnetic is continuous; but practically the temperature can be determined within a range of several degrees. To this temperature or to the temperature at which the magnetisation changes rapidly, several names are given, that is:—

1. Critical point (Kritischer Punkt, point critique).
2. Critical range.
3. Curie's point (Curiescher Punkt, point de Curie).
4. Point of transformation (Umwandlungspunkt, point de la transformation).

The first name was given by J. Hopkinson, and the second is used by the metallurgists. This name is very convenient if it is used to cover vaguely an interval of several ten degrees in the vicinity of the temperature at which the change of magnetisation or the heat evolution or absorption takes place most rapidly. In the present paper the author found several occasions to use the name in such a sense. But, strictly speaking, the interval of the temperature is too large to be properly called "a range"; indeed it is practically impossible to determine exactly the lower limit of the range. Hence the name, if it is used in a definite sense, is not quite correct. The third name, "Curie's point," does not seem to be properly termed; for as to the said transformation, the work of Hopkinson, the first discoverer of the critical point, is more valuable than that of P. Curie. The fourth name is a little misleading; for the name signifies that the transformation takes place at the temperature, but in reality the temperature is one at which the transformation terminates. Hence it seems to the author the oldest name, "Critical point," is the most recommendable, signifying thereby the temperature at which the ferro-magnetism practically vanishes.

DISCUSSION.

Sir **Robert Hadfield**, F.R.S., Past-President, in summarising Mr. Kotaro Honda's paper, "On the Nature of the A2 Transformation in Iron," said the paper was, he believed, the first that had been received by the Institute from a Japanese scientist, and the Council had accepted it with the greatest pleasure. He (Sir Robert) had been in correspondence with Professor Honda at Tokohu University last year, and found he had been making some very excellent researches. He had therefore suggested that he should give the Institute a paper. The paper bore in a very important way on the discussion of various allotropic modifications that had been before metallurgists in the last few years. Quite recently a new scientist, Mr. A. E. Oxley of the Sheffield University, submitted an excellent paper to the Royal Society "On the Influence of Molecular Constitution and Temperature on Magnetic Susceptibility." That being presented by Sir Joseph Thomson, it might be taken for granted that the subject was a valuable one. He had been corresponding with Mr. Oxley, and had received from him a letter to the following effect:—

> "The change of internal energy (potential) of the iron as we pass from above to below A3 is due to the closer packing of the molecules. There may be an accompanying distortion, but this is slight, and cannot be regarded as indicating allotropic modification. The thermal energy evolved is just the heat of transition from the more open packed cubic system to a closer packed cubic system. The internal atomic energy will not be appreciably changed, for the atomic structure of the molecule below and above A3 is the same. It is known that transformation from ozone to oxygen is accompanied by a thermal evolution; also the conversion of white phosphorus into red and the molecular transformation of sulphur S2 to S8 are exothermic. Moreover, the thermal evolution of these intramolecular changes are enormous compared with that in any transition from the liquid to the crystalline state or from one crystalline state to another. The large thermal evolution accompanying intramolecular change is, in my view, the thermal energy indicating allotropic change. The thermal evolution on cooling through A3 is not due to these causes, for the molecule of iron above and below A3 is the same atomic constitution. There will be a thermal evolution at A3, however, and this is the latent heat of transformation from the open to the close-packed assemblage of molecules. This latent heat is small compared with the thermal evolution accompanying allotropic change. (The smallness of the latent heat compared with the 'heat of allotropic change' is consistent with the smallness of the molecular distortion accompanying the crystallisation as compared with the abrupt change of atomic constitution of the molecule met with in the oxygen to ozone transformation.)"

Sir Robert thought that presented quite a new way of looking at the important subject so ably dealt with by Professor Honda, and he brought those remarks to the notice of his friend Dr. Stead, who would probably have something to say regarding them. He thought scientists often adopted a method of presenting diagrams that was not altogether the best mode of representing the changes. In the changes in the transformation of iron, known as the critical points, there was often a tendency to overlook the extraordinary change in magnetism that took place. He had prepared two diagrams which showed, side by side with the increasing temperature and the changes in the α-β-γ range, the exact percentage of specific magnetism. Many people were under the impression that when the critical change in iron took place

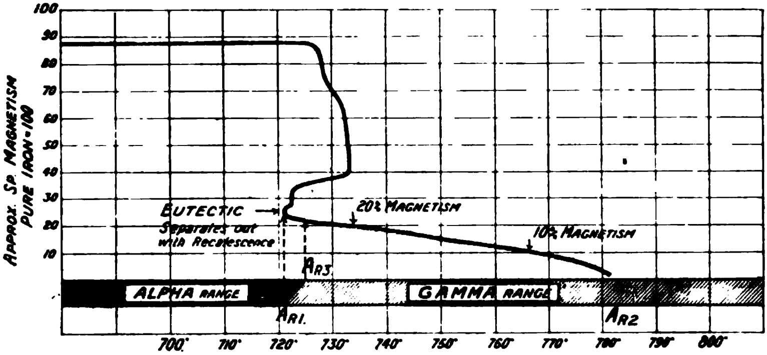

FIG. 1*a*.—Effect of Temperature on Magnetism of 0·8 per cent. Carbon Steel.[1]

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
0·80	0·10	0·016	0·012	0·30

The maximum value of the magnetism on this curve is taken as 88 per cent. of pure iron, *i.e.* 95 per cent. the value of a 0·8 per cent. carbon steel when cold, less 7 per cent. the magnetism of the cementite, which is non-magnetic at these temperatures.

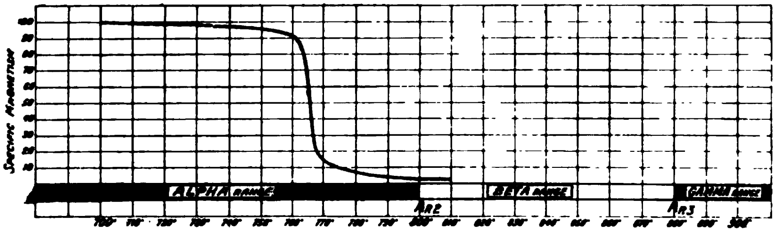

FIG. 2*a*.—Effect of Temperature on Magnetism of Pure Iron ("Kahlbaum").[2]

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[1] Based on Honda's present paper, and on Honda and Takagi's paper, "Transformations of Iron and Steels at High Temperatures."

[2] *Ibid.*

magnetism entirely disappeared, but that was not so; quite a considerable percentage of specific magnetism continued for a long time after the change point, and the diagrams brought out very well where the changes took place. (See Figs. 1*a* and 2*a*.)

With regard to the allotropic side of the question, Sir Robert said he would like to refer to the work of Mr. Oxley in his paper to the Royal Society above mentioned. The latter had given his opinion of the A3 point by stating that the rearrangement of construction, which he considered took place at that point, was not one necessarily involving change of crystalline symmetry, but merely a smaller distance of separation of the molecules below A3 than existed above, the direction of that closer grouping being that of spontaneous magnetisation and therefore characteristic for each crystalline grain. The variation of the molecular distances in the two perpendicular directions would be of small importance from a magnetic point of view. On the other hand, they would be of great importance from the points of view of magnetic structure and thermal expansion.

It might be mentioned that Mr. McCance had, the previous year, supported views of that nature in a paper which he read before the Iron and Steel Institute. If such definitions were accepted, it was quite clear that iron was not allotropic. In other words, the views held and fought for so long by Dr. Arnold, himself (Sir Robert), and others were now shown to be correct.

It should be stated that as both the iron and nickel used by Professor Honda were made by the Kahlbaum Company, a firm of considerable experience in the manufacture of pure metals, it was probable that the specimens on which he carried out his experiments were pure. The cobalt used was from Messrs. Johnson & Mathey, and therefore was no doubt of quite suitable quality.

Dr. J. E. **Stead**, F.R.S., Vice-President, said that for the previous two months he had had a most interesting and stimulating correspondence with Sir Robert Hadfield upon the question of whether or not there was such a thing as γ allotropic iron. Considerable doubt had been expressed in certain quarters as to the existence of β-iron. The feature of Mr. Honda's paper was that, in order completely to destroy β, he accepted the phenomena at A3 as indicative of a change from one allotropic state to another. Benedicks, and almost all the metallurgists of the world, were, on the latter conclusion, in agreement. At A3 there was a contraction or a coalescence of the molecules, which was another way of saying there was a contraction. There was also a disturbance in the electrical and magnetic properties, and a disturbance in the thermal properties, and, what was to his mind stronger evidence than anything, the crystallisation that took place in passing through A3 (which was not referred to by the author). Practical men were always saying that it was speaking in the air to talk about such changes, and that nothing could be shown in the finished product which indicated any of those things referred to by the author, that they were illusive, going and coming, with no indication in the iron, when cold, of any change, but that the reverse was the case when grossly crystalline iron was heated through Ac3. The coarse-grained iron became fine crystalline iron, and instead of being brittle and dangerous it became ductile and strong. That indicated a marvellous internal revolution. After all, names were unimportant; it was the internal physical change that mattered. Those changes might be called by any other name than allotropic so far as the arguments on the hardening of steel were concerned. It was internal physical change which it was now suggested should be called by another name. Osmond and others regarded as indication of allotropy an internal physical change unaccompanied by a change of state at a critical point. That being so, β was undoubtedly an allotropic modification of iron. Mr. Honda and others said that the β change was not a point, that it was spread over a big range, and that therefore it was not right to conclude that it was an indication of allotropic change. Some of his friends were anxious to give β its quietus. He thought they would have accepted γ as the destroyer, but they now said that γ itself did not exist. Did they not both exist? It all depended upon the definition of what was an allotropic change. He (Dr. Stead) was quite prepared, and he supposed every one in the room was prepared, to give it another name if necessary, but it was most important in the first place there should be an accepted definition of allotropy. He was trying to arrive at such a definition.

Professor H. **Le Chatelier**, Member of Council, congratulated himself on finding that the explanation he had given ten years ago as to the magnetic transformation point of iron was now being generally adopted. The experiments of Mr. Kotaro Honda, like those of Dr. Benedicks, had greatly contributed to clarify the views relating to that subject. The principal reason for not regarding that transformation as a change of allotropic state was that it was progressive. To demonstrate that progressiveness was somewhat difficult to effect in the case of iron, on account of the high temperature at which the transformation occurred. It could always be objected, as Mr. Burgess had done, that the inequality in the temperatures from one point to another in the sample was the cause of the phenomena observed. On the contrary, by bringing the researches to bear upon nickel, the magnetic transformation point of which was in every way similar to that of iron, although occurring at a considerably lower temperature (below 400°), it was possible, with absolute certainty, to affirm the progressiveness of the transformation. In order to make the experiment, he (Professor Le Chatelier) had taken a bi-metallic spiral, made with one layer, formed of two strips of equal thickness, one consisting of iron and the other of nickel. On heating, the unequal dilatation of the two metals led to a condition of torsion, which could be measured with extreme accuracy by means of a mirror fixed at the end of a stem, soldered on the upper end of the spiral. By those means absolute uniformity of temperature could be obtained, on placing the spiral under investigation in a glass tube, which was soldered into a rather larger external tube. Within the interval between the two tubes, sulphur was placed, and made to boil under varying pressures, so as to obtain temperatures which were definitely fixed by the boiling points. By such means it could be established beyond all question of controversy that the transformation was a gradual one.

Dr. W. ROSENHAIN, F.R.S. (Teddington), wished to draw attention to a field of research which had been taken up in recent years, and which he thought must altogether modify the ideas held on allotropy; he referred to the work of Professor Bragg on the reflection of Röntgen rays by crystals. It sounded very far removed from metallurgical matters, but it had a very direct bearing on the question, for it was shown that it was possible by means of the Röntgen rays spectrometer to ascertain the exact distribution in space of the atoms of the crystals. The crystals had been mineral crystals, but the investigation had now been extended to metallic copper, and no doubt would shortly be extended to iron and other metals. The point of vital importance was that the investigators had shown that the crystal structure was built up not of molecules but of atoms. If their view were well founded—and he believed it was receiving universal acceptation—it meant that there was no such thing as a molecule in the sense in which molecules were thought of in liquids and gases in the crystalline solid, and that a crystal was the next unit after the atom. If that were the case, what was meant by an allotropic change in a crystalline solid? It could only mean one thing, that the atoms were arranged differently in the various allotropic conditions, and that there must be some reason why they arranged themselves in one fashion in one range of temperature and in another fashion in another range of temperature. Whether the change from one to the other was sudden or gradual made no fundamental difference. He thought it was necessary to look for a change in the atom itself. If that were the case, all the discussion as to whether it was allotropic or not became a question of words, and he felt very strongly in agreement with what Dr. Stead had said on the subject—that, call it allotropy or anything else, there was a series of deep-seated, far-reaching internal physical changes to be explained and taken into account when considering the behaviour of steel during cooling, slow or rapid.

CORRESPONDENCE.

Dr. GEORGE K. BURGESS (Bureau of Standards, Washington) wrote that Professor Honda had rendered a real service in collecting together in readily accessible and compact form the essential results of his very comprehensive experiments on the properties of iron at high temperatures, and those observations undoubtedly were of great value for the interpretation of the A2 and A3 transformations of iron in terms of "allotropy."

Professor Honda laid down the definition: "An allotropic transformation is a change in a substance from one phase to another at a definite temperature," and he then proceeded to show from his interpretation of his own and other experiments that the A2 transformation took place over a considerable temperature interval and was not therefore an allotropic transformation "in the ordinary sense of the word." Professor Honda admitted, however, the need of the term "critical point" to define the end (on heating) of the A2 transformation, and would still keep "for convenience" the name β-iron for the state of iron lying between A2 and A3. In other words, it was practically impossible to get along without β-iron, because it was a state—but not a phase—bounded by two transformations, one of which was "allotropic" and the other not.

The question of whether or no in a given case there was "allotropy," as had been stated many times, was a matter of definition. It was questionable if the definition given by Professor Honda was sufficient, since it excluded the A3 transformation, for the reason that no one had ever been able—even by reducing the observations to zero rate of heating or cooling, as was done by Burgess and Crowe[1]—to make Ac3 coincide with Ar3, although those A3 transformations were usually found to start at about the same temperature and spread over some 25° up and down, the maxima of Ac3 and Ar3 being found to differ for zero rate by at least 10°. On the other hand, a change of phase as from solid to liquid—and in many cases in the solid state—took place on cooling and on heating at exactly the same temperature. It was also generally recognised by physical chemists that there might be more than one type of allotropy, and a good description of several possible types with accompanying figures was given by Professor Benedicks in 1912.[2]

As to A2, the maximum and ending of Ac2 agreed exactly with the maximum and beginning respectively of Ar2 as measured by all physical methods which had been tried. In other words, the A2 transformation was reversible in all respects (like a change of phase such as a melting point), while the A3 transformation was not reversible in that it appeared to require a definite temperature interval (with Ac3 always higher than Ar3) for its completion. That the A2 transformation, although having a sharp maximum and ending on heating, was preceded by an anticipatory range of many degrees seemed probable, in view of all the observations. That would classify A2 as being essentially of the allotropic type II*a* of Benedicks,[3] a comparatively common type of transformation. It was highly desirable to come to a better understanding as to when a transformation should be called allotropic. As an example of the confusion of ideas on the subject, it might be recalled that Professor Benedicks[1] decided that the A2 point, as determined thermally by Burgess and Crowe, could not be an allotropic point because Ac2 equalled Ar2 exactly, it being a characteristic of allotropy, according to Benedicks, "that without exception an allotropic transformation point was found at a higher temperature on heating than on cooling." For Professor Honda, allotropy could not exist when the transformation was spread over a considerable temperature range, as he considered was the case of A2 but not for A3.

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[1] *Scientific Paper*, No. 213, Bureau of Standards, 1914.

[2] *Journal of the Iron and Steel Institute*, 1912, vol. lxxvi. p. 242.

[3] Benedicks, *loc. cit*,

It would, Dr. Burgess considered, be simpler and sufficient to call both A2 and A3 allotropic transformations, and to recognise that all such transformations were not exactly alike. He wished to call attention to certain aspects of some of the experimental results on which was based the interpretation of the nature of the A2 transformation. Referring to the thermal curves of Fig. 1 (Honda) and Fig. 2 (Burgess and Crowe) the latter was unfortunately drawn to an incorrect temperature scale, nor did it show the observational points as plotted in the original, which, for those reasons, was here reproduced as Fig. 3*a*. Too great importance should not be placed on the swings of the $q : \theta$ curves (*a* and *b* in Professor Honda's notation) of either Fig. 1 or Fig. 3*a* as they were caused, in large part at least, by other conditions than transformations in the iron samples. It was to be believed that the derived differential curves of Fig. 3*a* gave a very exact picture of the A2 and A3 thermal transformations in iron and of their location. It was evident that, thermally, A3 differed from A2 mainly in magnitude, and in having Ac3>Ar3, whereas Ac2 = Ar2, which Ac2 maximum might well be, as previously stated, the end point of a transformation starting at a low temperature not definitely located. The less sharp contours of Professor Honda's curves appeared to be due to his relatively long sample and consequent uneven temperature distribution throughout its mass. That requirement, in exact work, of uniform temperature over the sample, in his (Dr. Burgess') opinion, had been met in very few experiments on the properties of iron at high temperatures. In Fig. 3*a* it was seen that Ac2 was located at exactly the same temperature as Ar2, namely, 768° C., whereas Professor Honda found Ac2 considerably above Ar2. At his request an examination had been made of Professor Honda's iron at the Bureau of Standards, with the assistance of Mr. H. Scott. The heating and cooling curves for that iron showed a slight difference, 4 or 5° C., for Ac2 – Ar2; whereas for gas-free pure iron Ac2 was always found to equal Ar2. Professor Honda's iron gave Ac2 = 767° and Ar2 772° C. His temperature scale appeared from Fig. 1 and these observations to be about 20° C. too high over the A2, A3 region.

As to the use of the temperature at which $dq/d\theta$ was the maximum in defining the location of A2—a practice Professor Honda criticised—the principal advantage in its use was the sharpness with which that temperature could be located. In fact, for some 130

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[1] American Institute of Mining Engineers, *Bulletin*, December 1913.

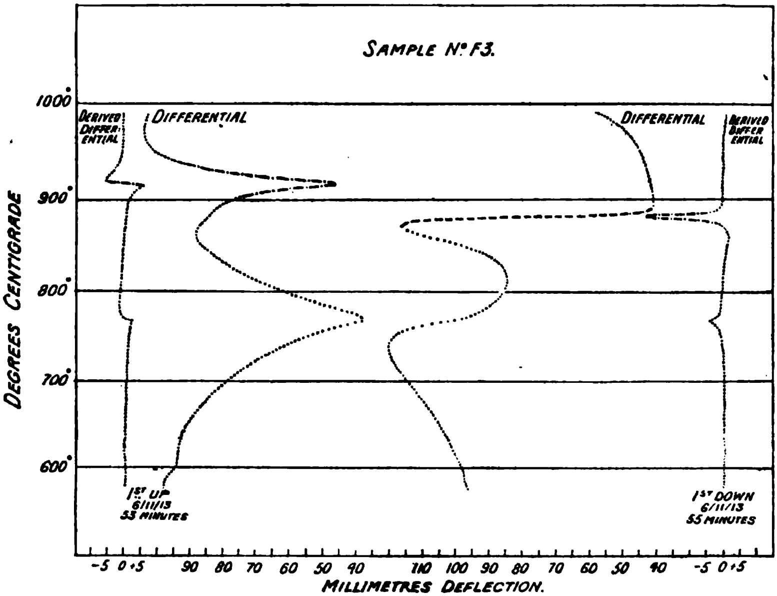

FIG. 3*a*.—Comparison of differential and derived differential curves.

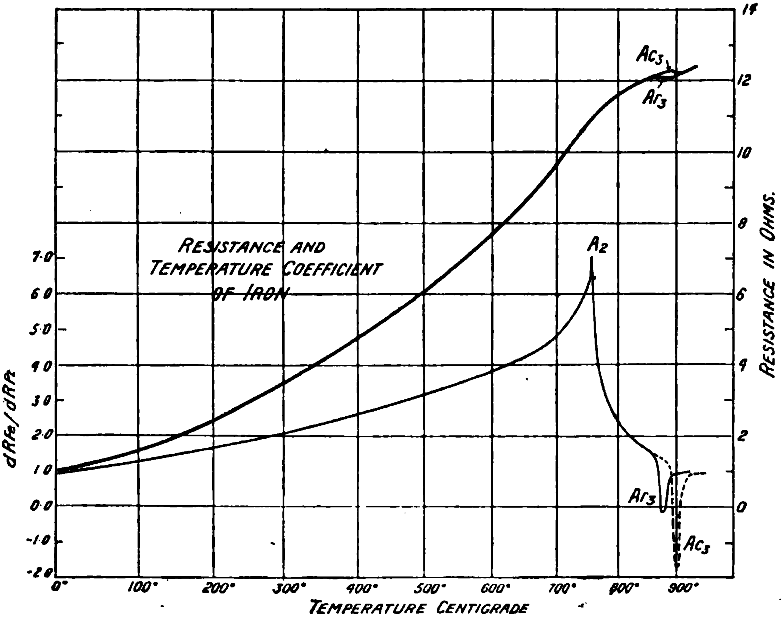

FIG. 4*a*.—Curves of electrical resistance.

curves for pure iron it was found by Burgess and Crowe (*loc. cit.*) to be practically independent of rate and reproducible to 0·5° C., and that temperature had been found to be a convenient one with which to calibrate thermo-couples, and was being so used.

Regarding the magnetic measurements and Professor Honda's interpretation of the behaviour of iron below the A2 region, it seemed to Dr. Burgess that the magnetic properties for very weak magnetising fields were of the greatest interest in interpreting the nature of A2; for, accepting Professor Honda's hypothesis of spherical ferro-magnetic and ovoid or elongated para-magnetic molecules, a weak magnetising field strained the iron least, and the resulting $I:\theta$ curve, such as in Fig. 6, due to Professor Hopkinson, and for which $H=0{\cdot}3$ would appear to be more truly representative of the iron used in a study of thermal, electrical, and dilatational and other physical properties than iron in a field of relatively high values of H, which would be expected to introduce some ovoid or para-magnetic molecules below A2 and greatly distort the $I:\theta$ curve proper to magnetically unstrained iron. If that were accepted, the Ac2 point was an exceedingly sharp transformation preceded by a short anticipatory region as measured magnetically (see Fig. 6). On cooling also, it was to be noted that Ar2 began with great abruptness, as measured magnetically as well as thermally.

The electrical resistance of iron, as Professor Honda pointed out, was also of considerable interest, but in view of the fact that his curve for $R:\theta$ for pure iron, as recorded in Fig. 15*b*, gave an incomplete and partially erroneous idea of that phenomenon, the $R:\theta$ and $dR/d\theta:\theta$ curves, as determined by Burgess and Kellberg,[1] were shown in the accompanying Fig. 4*a*. The A2 point was again strictly reversible, and the $R:\theta$ curve here passed through a point of inflection shown as a cusp in the $dR/d\theta:\theta$ curve. Ac3 was seen to lie above Ar3 as also found for all other phenomena; they both began, however, at the same temperature. There was not, properly speaking, a "kick" at A2 in the $R:\theta$ curve, but there evidently was one at A3. The behaviour at Ac2, in electrical resistance, more nearly resembled that for a change of phase, as from solid to liquid when the resistance usually increased vertically, than did the behaviour at Ac3, at which point the resistance actually dropped at first, accompanying the phenomenon of recrystallisation.

The argument at the end of Section 6, that "the discontinuity (measured by expansion) to be expected at A2 point should be of the same order of magnitude as that at A3 point, if it were to be considered as a proof of allotropic change," did not seem to him (Dr. Burgess) to be valid; for there appeared to be no reason to expect that all the thermal effect would produce a volume change, especially in view of the admittedly large and abrupt change in magnetic properties at A2. In fact, it was possible to have transformations involving no volume changes whatever, as Tammann and others had shown.

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[1] *Journal of Washington Academy*, 1914, vol. iv. p. 435; *Scientific Paper*, No. 236, Bureau of Standards, 1914.

There were many other important items in Professor Honda's very interesting paper which Dr. Burgess would like to discuss, but he felt he had already said more than enough to make his position clear. It was that, from the evidence at hand, it was equally justifiable to call both A2 and A3 allotropic points, in the ordinary sense of the word; but if a limited definition were framed to indicate an allotropic change, there was a risk of excluding inadvertently both A2 and A3, as did Professor Honda's definition. A definition of allotropy that, within the limits of our present knowledge, would exclude A2 and admit A3 (if that differentiation were desired, as would appear from an examination of recent literature) was the one suggested tentatively by Burgess and Crowe (*loc. cit.*), namely, "An allotropic transformation is one accompanied by crystallographic change."

Dr. Cecil H. Desch (Glasgow) wrote that the question whether the A2 transformation should be regarded as allotropic or not had now become mainly one of definition. The whole conception of allotropy had been altered by such studies as those of sulphur by Alexander Smith and others, and of phosphorus by Smits. It had been shown that complex equilibria were possible between different modifications of the same element, even within a single phase. When the two modifications were immiscible, and so formed separate phases, a sharp transformation point was observed, but when they were miscible, forming a single liquid or solid phase, the transformation extended over a range of temperature. Otherwise the phenomena were of the same class, and there did not seem to be any good reason why the term allotropy should be applied to the change rhombic $\rightleftarrows$ monoclinic sulphur and refused to the change $\alpha \rightleftarrows \beta$ iron, merely on the ground that the latter extended over a range of temperature. That the evolution or absorption of heat at A2 was only one-third of that at A3 was also an insufficient reason for rejecting the term allotropy in that case. The writer did not wish to be understood as accepting Professor Benedicks' view as to the nature of the A2 point in its entirety, but he wished to lay stress on the essential similarity of dynamic and ordinary allotropy, a similarity which fully justified the use of the same name for both conditions.

In regard to changes in the crystalline state, it did not appear to be necessary that a crystalline re-arrangement, corresponding with an allotropic change, should produce any alteration in the visible external form of the crystals, or in their behaviour on etching. Several different cubic space-lattices were possible, and only the very searching X-ray method revealed the internal structure fully. In view of the changes in other physical properties, it was highly probable that an alteration of the space-lattice occurred during the course of the A2 change. The presence of two interpenetrating space-lattices, corresponding with a mutual solid solution of the two modifications, was quite possible.

Professor Honda's most valuable contributions to that subject had added greatly to the knowledge of the facts concerning the transformations of iron and steel, and the writer only wished to suggest that the conception of allotropy was wide enough to embrace the new facts.

Dr. W. H. **Hatfield** (Sheffield) wrote that he considered Professor Honda's paper a very important contribution to the weight of evidence produced of late, which would need to be taken into account when a decision was made as to the real meaning of the critical points in iron.

The experimental work upon the influence of the stronger field was particularly interesting. As regards the author's deductions, he (Dr. Hatfield) considered they were generally substantiated by the data advanced, and quite agreed with the view stated in the first paragraph. Turning to page 235, Fig. 19, it was of interest to see Mr. Honda's interpretation of Rosenhain and Humfrey's results, and in that connection he (Dr. Hatfield) might say he had always held the same view.

There was one further point he wished to mention, namely, the position of the critical carbon change point. According to the Figs., particularly Fig. 9*d*, it would appear to occur at 760° to 770° C. Was not 740° C. nearer the absolute temperature, or was it to be understood that the author found the magnetic dip did not coincide with the formation of the solid solution? That was extremely important, and it would be of interest to know exactly the means taken by Mr. Honda to insure simultaneous magnetic and thermal readings.

Mr. A. **McCance** (Glasgow) wrote that the clear statement which Professor Honda had made embodied much research on the magnetic properties of iron and steel, and his main conclusions as to the nature of the A2 point would by now be generally admitted. Loss of ferro-magnetism had two causes. The first was the result of thermal agitation of the molecules, and made the intensity of magnetisation a continuous function of the temperature. On heating, at the transformation temperature, the fall in magnetic intensity was rapid, but it was still continuous, and on cooling an equally rapid rise took place at the same temperature. Such was the behaviour of the so-called reversible magnetic steels, and those had a thermal change point associated with their loss of ferro-magnetism. That thermal change point, however, was always lower than the temperature at which the magnetic intensity became inappreciable, since its magnitude was proportional to

$$I.\frac{dI}{dt}$$

and would become very small when either I or $\frac{dI}{dt}$ was small, while its maximum value would be between those limits. Thus in iron the thermal point A2 occurred at 765° C., while magnetically it occurred at 795°; with nickel the respective temperatures were 340° and 360°, and with cobalt about 1020° and 1070°. That thermal effect was really due to an abnormal variation in the specific heat, and no change took place in the crystalline form of the material. The form of the intensity curve was in every case like that of the curves in Fig. 7 in Prof. Honda's paper.

The second cause was due to a change in crystalline symmetry from α to γ, and gave rise to the irreversible magnetic steels. It was totally different in origin from the first, and the two changes should not strictly be classed together in the same diagram when both might occur, as in nickel iron alloys. That mode of change was discontinuous, and the shape of the curve of intensity was entirely different from the first, as shown in Fig. 9*c* and 9*d*, which were typical. The curves in Fig. 9*a* were really very complicated, since they were the result of the superposition of both the above effects. Up to about 740° C. there was the continuous decrease in intensity, above that there was a discontinuous decrease due to the transformation of the eutectic α iron to γ, and then to the end there was the normal continuous decrease accelerated by the conversion of the α iron to γ as the temperature rose.

In that connection he (Mr. McCance) wished to ask Prof. Honda what temperature standards he used for his thermo-couples, since the temperatures given in many of his curves seemed distinctly higher than those usually associated with the thermal change points in iron. In Fig. 10*c* Ac1 occurred at 760° and Ar1 at 719°, whereas they were usually given about 20° lower for similar steels.

The first question which Prof. Honda raised was his statement that the continuous thermal loss of intensity on a rising temperature was carried beyond the γ-α transformation point and gave rise to the A2 point in all steels at approximately the same temperature. His curves 4*d* to 4*l*, however, were not conclusive, since they were not sufficiently straight to enable the temperature the change point occurred at to be stated—if it could be argued that a change point was actually visible in them at all—and the magnetic curves in Fig. 9*c* and 9*d* did not show any appreciable intensity above the eutectic point. The evidence was indeed all against such a supposition, and he (Mr. McCance) did not think that γ-iron could be held to become magnetic until it was shown that non-magnetic austenite could be made magnetic without any appreciable change in its specific volume.

He entirely agreed with the curve of the susceptibility of pure iron given in Fig. *b* by Professor Honda, in which the normal continuous decrease with temperature was broken by a discontinuous decrease due to the transformation of α iron to γ at the A3 point.

Prof. Honda's theory of magnetism was interesting, but it seemed to raise difficulties as great as those it sought to explain. Was there any experimental justification for the statement that with "increase of temperature the molecules begin gradually to deform." Although crystals might expand at different rates along each axis, it was no proof that the molecules themselves changed their shape, but only that their relative axial distances varied. Views respecting the solid state of aggregation were at the present time undergoing tremendous changes by the results of investigations into the relative positions of atoms in crystals, and it might be that when the new ideas became definite much that could not at present be understood would become simple, and it was to be hoped that the intricacies of ferro-magnetism would be among the first to be illumined by the clearer light.

Professor Honda deserved great praise for his paper, which was an admirable statement of present knowledge, and it was helpful by reason of its assurances that the allotropy of iron was really simpler than many were willing to believe.

[NOTE.—The inevitable postal delays consequent on the war having prevented the author's reply from being received in time to be included in the present volume, facilities will be accorded Professor Honda for the publication of his reply in a subsequent issue of the *Journal*.—EDITOR.]

THE DIFFUSION OF CARBON IN IRON.

By F. W. ADAMS, B.Sc.
(Wiggin Scholar in Metallurgy, University of Birmingham).

Sir F. Abel, in 1881,[1] first indicated the existence of a carbide of iron of the formula Fe_3C, and most metallurgists now accept this formula as representing the composition of the most important compound of iron and carbon. The conditions of stability of this carbide, however, are still subjects of controversy.

During the interval that has elapsed since Abel's original discovery many investigations have been conducted with the object of determining the conditions of formation, and the properties of other carbides of iron. The results of Wittorf's[2] researches indicate the probable occurrence of three additional carbides, having the respective formulas, FeC_2, Fe_4C, and FeC. As proofs of the existence of these carbides are not yet complete, and their range of stability does not extend below 1200° C., a consideration of their influence on the diffusion of carbon in iron is not included within the scope of the following investigations.

In a paper which was presented to this Institute in 1897 by Mr. G. P. Royston,[3] an experiment was described which was conducted as follows:—

A piece of steel, containing 0·95 per cent. of carbon, was placed in a porcelain tube, and heated *in vacuo* at 900° C. for twelve hours. The sample weighed practically the same after as before heating. Two pieces of mild steel, containing 0·15 per cent. of carbon, were then placed in the tube along with the previous high carbon sample, but not in contact with it. These three pieces were then heated for twelve hours *in vacuo* at 900° C. This treatment produced practically no alteration in their weight. The high carbon specimen was then placed in contact with the two low carbon pieces, and the three samples subjected to the same treatment as in the previous cases. The specimens were then cooled *in vacuo*, and reweighed. The results showed that the low carbon pieces had increased in weight, whilst the high carbon piece had lost an amount equivalent to that gained by the low carbon pieces. On determining their respective carbon contents after this treatment, it was found that the percentage loss of carbon in the high carbon pieces was exactly balanced by the percentage gain of carbon in the low carbon pieces. From the results of this experiment it would seem that the carbon only had diffused from the inner high carbon piece to the outer low carbon pieces. Mr. Royston suggested that the carbon was apparently in solution as such, in the iron, at the temperature of the experiment, viz. 900° C., and should in that case obey the ordinary laws of diffusion, and diffuse through the iron until the pressure of solution was equalised throughout.

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[1] *Proceedings of the Institution of Mechanical Engineers*, 1883, p. 56.
[2] *Journal of the Society of Chemical Industry*, 1912, p. 388 (abstract).
[3] *Journal of the Iron and Steel Institute*, 1897, No. I. p. 172.

Reference was made to the above experiment in a paper on the "Diffusion of Elements in Iron," by Dr. Arnold and Mr. A. McWilliam.[1] In the section of their paper dealing with the diffusion of the element carbon into iron, the authors conclude, from the results of their experiments, that carbon diffuses in the form of a carbide from a high carbon steel into a specimen of soft iron, when both pieces are heated in immediate contact *in vacuo* for several hours, within the temperature range of 900° to 1000° C.

Professor Turner also drew attention to Mr. Royston's experiment in the discussion on a paper by Professors Arnold and Read,[2] and the opinion was expressed that if the iron carbide were in entropy at that temperature it ought to have passed out of the high carbon steel into the low carbon steel with a difference in weight due to the carbon alone. Mr. Royston's experiment seemed, at all events at first sight, to prove that carbon existed in the free form at that high temperature, but that was not what he (Professor Turner) was inclined to believe.

The following research was undertaken with the view of confirming Mr. Royston's experiment and, if possible, to obtain further evidence to prove whether, at temperatures between 900° to 1000° C., carbon diffuses as such or as iron carbide.

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[1] *Journal of the Iron and Steel Institute*, 1899, No. I. p. 85.

[2] *Ibid.*, 1912, No. I. p. 231.

EXPERIMENTAL METHOD.

The apparatus used in the investigation consisted of a royal Berlin porcelain tube, 1 inch in diameter, and glazed both inside and out. The samples to be treated were placed in this tube, which was heated by an electric furnace of the resistance type. It was found necessary to water-cool the ends of the porcelain tube by means of two coils of ¼-inch diameter copper tube. One end of the porcelain tube was connected to a mercury exhaust pump, and the other end closed. For these purposes special quality rubber bungs, covered on the outside with sealing-wax, were used. To protect the ends of these rubber bungs from the scorching effects of radiant heat, ten discs of mica were threaded on each of two 2-inch lengths of glass rod. One of these was placed at each end of the porcelain tube, about 1 inch away from the inside ends of the rubber bungs. A platinum and platinum-iridium thermocouple, placed in contact with the porcelain tube, opposite the sample to be heated, registered the temperatures employed in the experiments. (See Fig. 1.)

MATERIALS USED.

The following table gives the analyses of the materials used in the investigations:—

	Silicon.	Manganese.	Sulphur.	Phosphorus.	Combined Carbon.	Graphitic Carbon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Steel 1 . .	0·094	0·39	0·035	0·1	1·40	
,, 2 . .	0·070	0·32	0·002	0·018	0·89	
,, 3 . .	0·070	0·23	0·027	0·030	0·466	
Dead-mild steel .	0·023	0·38	0·057	0·090	0·059	
Grey hæmatite cast iron .	0·963	0·69	0·010	0·025	0·37	3·83
White cast iron .	0·070	0·05	0·036	0·062	2·254	
Swedish bar iron	0·016	0·02	0·007	0·012	0·034	
Round bar steel .	0·339	0·43	0·06	0·024	0·985	

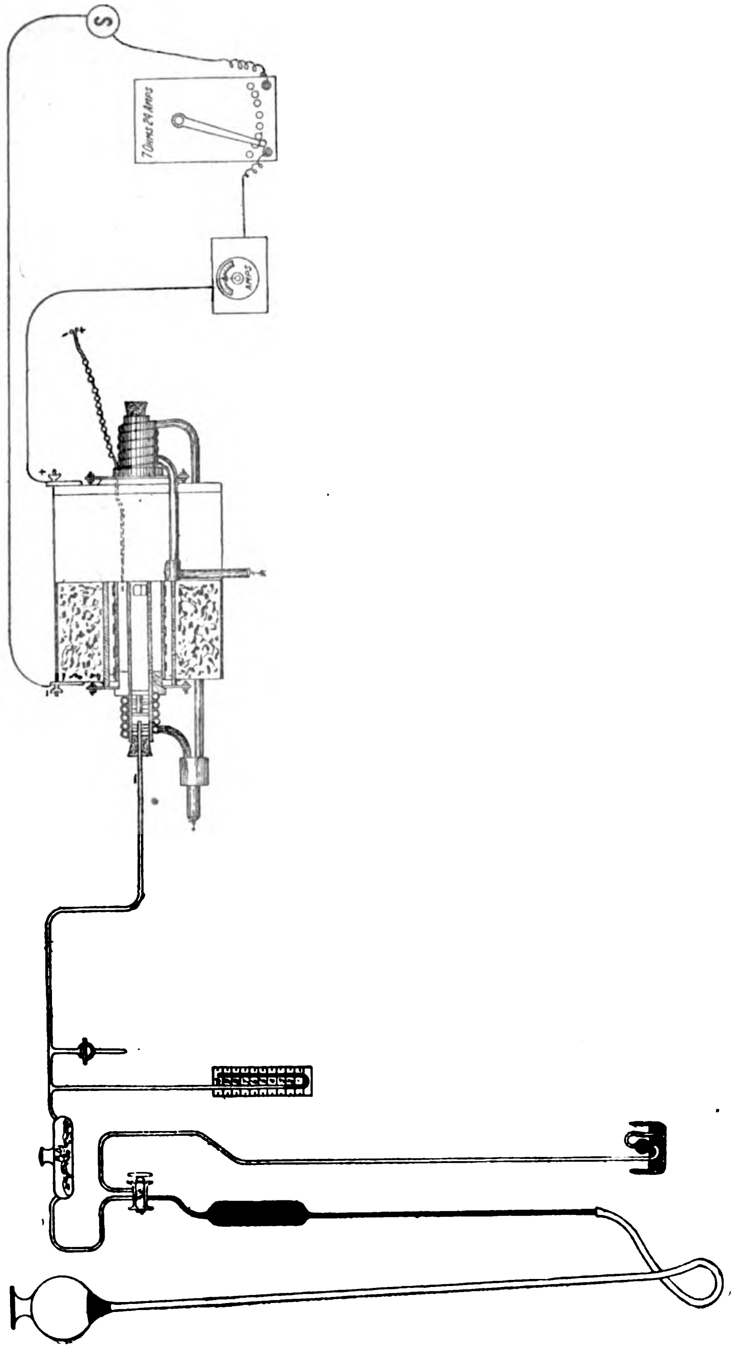

FIG. 1.—Diagram of Apparatus used for the Experiments.

Swedish bar iron was originally chosen for the experiments on account of its purity and freedom from elements which might affect the condition of the carbon during the diffusion. Mr. Guillet[1] points out that those elements capable of forming double carbides accelerate the absorption of carbon, whilst others, such for instance as silicon, tend to retard this process. In some of the later experiments the use of this material was abandoned in favour of dead-mild steel containing 0·06 per cent. of carbon. In this latter material the carbon is much more evenly distributed than in Swedish bar iron, and therefore gives a more reliable sample for the estimation of small variations in its carbon content.

PREPARATION OF THE SPECIMENS.

The specimens used for the experiments were carefully machined, polished, washed in ether to remove grease, and then accurately weighed. Where necessary, the specimens were bound round with soft iron wire to keep them in position during treatment.

Samples for treatment were placed in the porcelain tube, from which the air was then exhausted to a pressure of less than 1 millimetre of mercury. After being heated for the required length of time, the specimens were allowed to cool *in vacuo*. The varying quantities of gas, which were evolved from the specimens when heated *in vacuo*, were removed at intervals during the experiment. The larger portion of these gases, however, was removed during the earlier stages of heating—that is, after a temperature of 900° C. had been attained. In all cases, after this treatment, the specimens were removed from the tube and found to be quite bright and clean, and were examined microscopically, and where possible reweighed.

It was decided to carry out the experiments at temperatures between 900° to 1000° C., since, within this range of temperature, iron exists in the γ modification, and, when in this condition, readily takes up carbon.

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[1] *Journal of the Iron and Steel Institute*, 1912, No. I. p. 545.

Experiment 1.

The first experiment was conducted as follows:—A solid steel cylinder containing 0·985 per cent. of carbon was carefully turned, polished, and made an exact push fit (cold) into a collar of Swedish iron, which had been accurately drilled and reamered out to size. This iron collar was cut longitudinally into two pieces, across a diameter, to facilitate the separation of the specimens after they had been heated in contact. The steel cylinder was enclosed between the two halves of the Swedish iron ring, and the whole bound round with soft iron wire to preserve the relative positions of the three samples. The compound specimen was heated *in vacuo* for nine hours between 900° to 1000° C. After cooling *in vacuo*, the specimens were reweighed. The results showed that both the Swedish iron pieces and the high carbon piece had lost weight. In the former case, this loss of weight was 0·027 per cent., and in the latter 0·039 per cent.

The surfaces of the two halves of the Swedish iron ring were copper plated, polished, and etched with picric acid. A microscopical examination of their extreme inner surfaces, however, failed to reveal any traces of carburisation.

Several metallurgists have already observed that iron and steel lose weight when heated *in vacuo* above 900° C. It is suggested by some investigators that this loss of weight may be due partly to the volatilisation of the iron itself, and partly to gases which are evolved from iron and steel when at a red heat. In this connection Mr. Boudouard[1] states that he has found that iron *in vacuo* begins to volatilise at 900° C., and that the phenomenon is very distinct at 1100° C.; Messrs. Ewen and Kaye[2] observed, when iron is heated to redness *in vacuo*, that, in addition to ordinary evaporation of the metal, a rectilinear projection of particles of iron also takes place. Professor Carpenter[3] found, on heating cast iron *in vacuo*, that, after repeated heatings, black rings were formed on the water-cooled ends of the porcelain tube. Analysis proved that these rings contained silicon, carbon, and hydrogen, which in his opinion would seem to suggest a volatile silico-organic compound. The present author observed in these experiments that similar black rings were formed on the water-cooled ends of the porcelain tube after repeated heatings of iron and steel *in vacuo.* Examination of these rings failed, however, to show the presence of constituents other than iron and carbon.

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[1] *Revue de Métallurgie*, 1908, vol. lxxiv. p. 69.

[2] *Proceedings of the Royal Society*, 1913, vol. lxxxix.

[3] *Journal of the Iron and Steel Institute*, 1911, No. I. p. 196.

The results of recent researches have proved that occluded gases exist in steel, and that these gases are, to a large extent, removed by heating the steel, *in vacuo,* below its melting point, the amounts of gas thus evolved diminishing with repeated heating of the metal. It might be supposed, in the case of wrought iron, that the process of manufacture would tend to preclude the occurrence of such gases. Since *in vacuo* above 900° C. wrought iron does evolve varying quantities of gases, it is possible that these gases may be produced by chemical action, at a red heat, between carbon and the oxides contained in the slag-particles disseminated through the iron.

Experiment 2.

To confirm the observation that iron and steel lose weight when heated *in vacuo,* two solid cylinders, one of Swedish iron and the other of steel containing 0·985 per cent. of carbon, similarly prepared, and of the same dimensions as those used in the previous experiment, were weighed and then heated *in vacuo* for nine hours at a temperature of 900° to 1000° C. On reweighing them, it was found that there was a percentage loss of weight of 0·036 gramme in the Swedish iron cylinder, whilst the high-carbon steel cylinder had lost 0·048 per cent. of its original weight.

Experiment 3.

Since, in the first experiment, no transference of carbon had apparently taken place, it was thought that the surfaces of the two specimens were not in sufficiently good contact. To verify this supposition, a highly polished steel cylinder containing 0·985 per cent. of carbon was made a tight driving fit, cold, into a collar of Swedish iron. Both specimens had been previously weighed. The compound bar was then heated *in vacuo* for nine hours at 900° to 1000° C. Since, on heating, the steel expands nearly twice as much as the Swedish iron, the contact between the two pieces at 1000° C. should be nearly absolute. After this treatment, separation of the two samples was found to be impossible, and therefore the two cylinders could not be reweighed. The compound bar was cut across, polished, etched, and examined microscopically. It was observed that distinct carburisation of the inner surface of the Swedish iron ring had taken place.

Experiment 4.

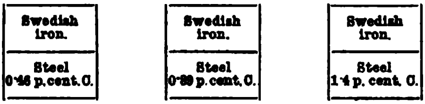
It is apparent, from the results of the previous experiment, that no data as regards the weight of carbon that had been transferred from the steel to the Swedish iron could be obtained. An attempt was therefore made to obtain sufficiently good contact between the surfaces of two specimens for carbon to pass over, by using flat pieces which could be separated and weighed after being heated in contact. For this purpose two flat pieces of Swedish iron $\frac{3}{4}$ inch × $\frac{1}{2}$ inch × $\frac{1}{4}$ inch, and one piece of steel 1·4 per cent. carbon of the same dimensions, were first of all shaped quite flat, and then ground one on the other by means of oil and flour of emery. These pieces were finally polished on chamois leather, covered with moist alumina. After careful weighing, the high carbon piece was placed between two Swedish iron pieces, the whole bound round with soft iron wire, and heated *in vacuo* for twelve hours at 900° to 1000° C.

Examination of the specimens after this treatment showed that intercrystallisation had taken place at points of good contact on their surfaces, and a sharp blow with a hammer was required to break them apart. Photomicrographs are shown of the fractured weld and of cross sections through the welded portions of the steel and Swedish iron. The latter pieces were backed with fusible metal, so that their extreme edges could be examined. It will be noticed that diffusion has taken place only at the points of welding. Dr. Stead[1] has drawn attention to the fact that iron and steel will crystallise or weld together at temperatures below their melting points, provided that the surfaces of the pieces are clean, and make good contact.

As far back as 1889, Coffin describes a similar phenomenon. He suggests that, as steel is highly carburised, the diffusion of a carbide of iron may probably play an important part in the union.

Experiment 5.

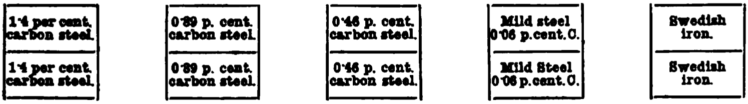
To ascertain whether varying amounts of carbon affect this welding property of iron and steel, three pieces of Swedish iron and three pieces of steel, containing respectively 0·46 per cent., 0·89 per cent., and 1·4 per cent. of carbon, were prepared as in the previous experiment. The dimensions of each were ¾-inch by ½-inch by ¼-inch. These samples were arranged as shown,



and heated in contact *in vacuo* for sixteen hours at a temperature of 900° to 1000° C. After this treatment, each set of specimens was broken apart, and it was found, in each case, that the fractured areas were approximately equal.

Experiment 6.

An experiment was now carried out to ascertain whether this welding is assisted or retarded by the presence of carbon in the specimens of iron or steel which exhibit this property. For this purpose five sets of duplicate specimens of the same size, and similarly prepared to those used in the previous experiment, were arranged in pairs as shown—


1·4 per cent. carbon steel.
1·4 per cent. carbon steel.
0·89 p. cent. carbon steel.
0·89 p. cent. carbon steel.
0·46 p. cent. carbon steel.
0·46 p. cent. carbon steel.
Mild steel 0·06 p. cent. C.
Mild Steel 0·06 p. cent. C.
Swedish iron.
Swedish iron.

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[1] *Journal of the Iron and Steel Institute*, 1911, No. I. p. 55.

After being heated *in vacuo* for sixteen hours at 900° to 1000° C., the duplicate specimens were broken apart, and the results are shown in photograph 5.

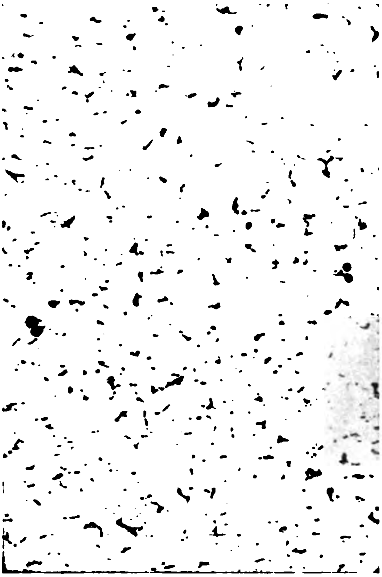
Experiment 7.

Two samples, one of dead-mild steel containing 0·06 per cent. of carbon, and the other of pure white iron containing 2·25 per cent. of carbon, were polished, and heated in contact *in vacuo*, for fifteen hours at 900° to 1000° C. The results showed that intercrystallisation between the two surfaces in contact had taken place to a marked extent. A microscopical examination of the polished and etched surfaces of the fractured weld showed that a considerable quantity of carbon had migrated from the white iron to the mild steel, but, contrary to expectation, no separation of graphite in the white iron had resulted from this treatment.

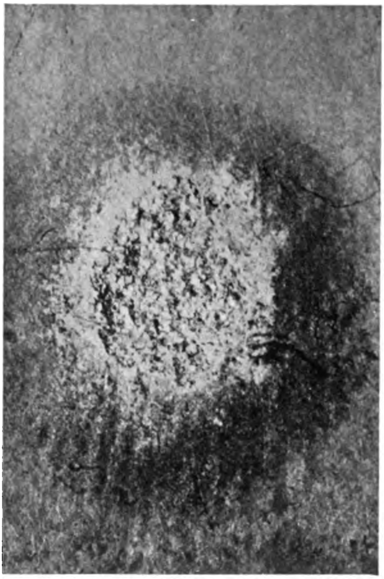
The above two specimens showed a larger area of welding than any of the samples similarly treated in Experiments 5 and 6. This may be due to the improved contact between the two pieces. White iron being uniformly hard, its surface is capable of taking a very high polish, and at the same time preserving an even condition.

This suggestion would appear to be confirmed by the following experiment, in which a piece of pure grey hæmatite iron was heated *in vacuo*, in contact with a piece of dead-mild steel, for fifteen hours at 900° to 1000° C. The result of this treatment showed that welding had taken place at three points only, on the surfaces in contact. The mild steel showed cementation at these points, but none was visible elsewhere on its surface. This fact seems to indicate that the harder portions of the surface of the cast iron had taken a better polish than the rest of the surface, and thus better contact between the white iron and mild steel had been secured at these points.

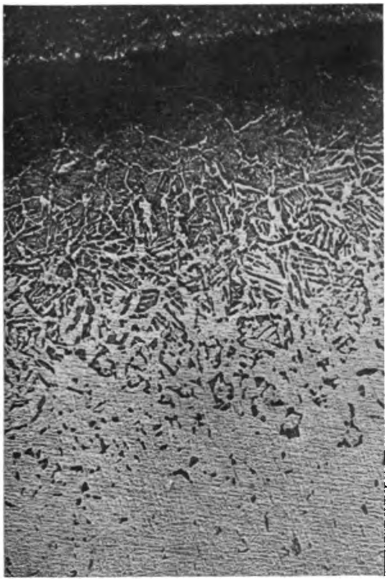
Two pieces of grey hæmatite iron of the same composition as that used in the previous experiment were polished and heated in contact *in vacuo* for twenty-two hours at 900° to 1000° C. No intercrystallisation between the surfaces in



No. 1.[1]



No. 2.



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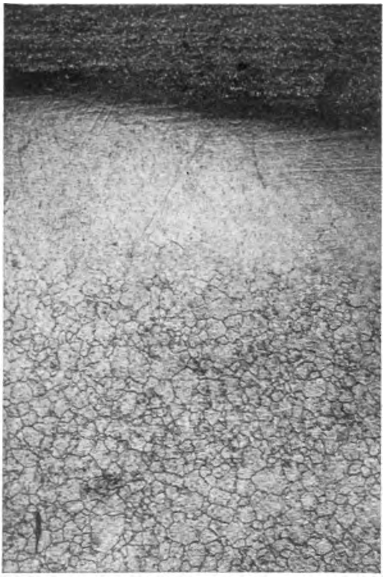

No. 4.

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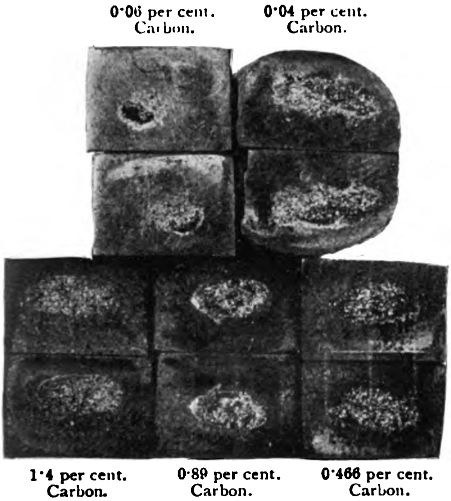
[1] For description of these and succeeding photomicrographs, see pp. 267–268.



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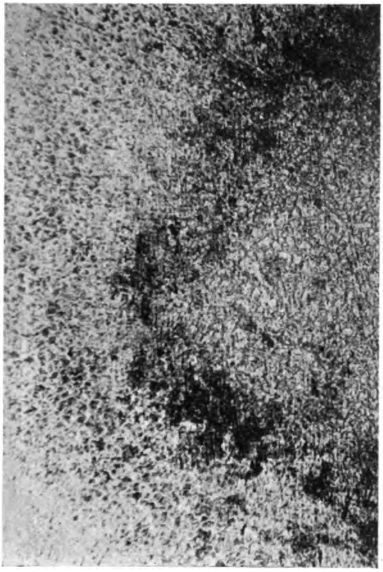

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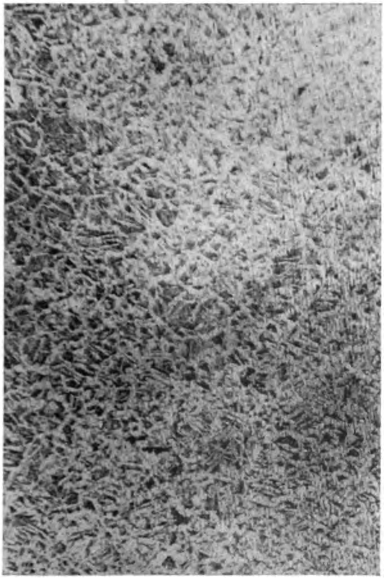

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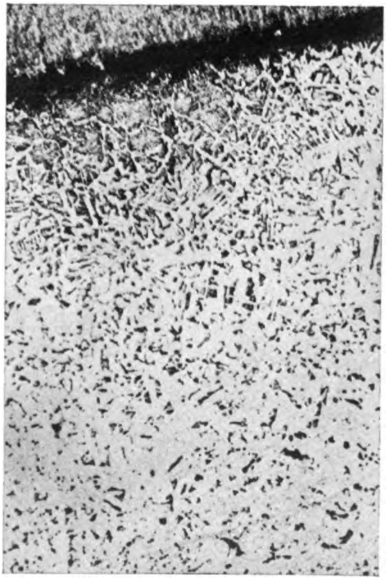

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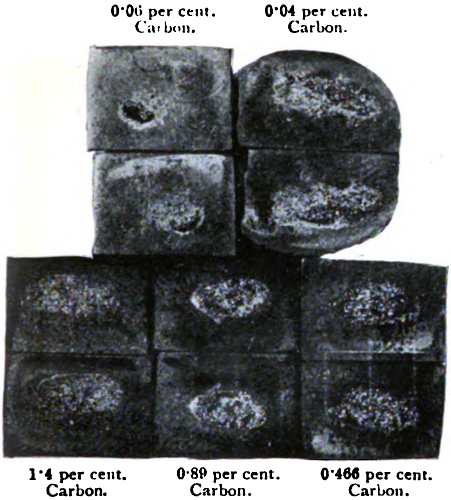
PLATE XLI



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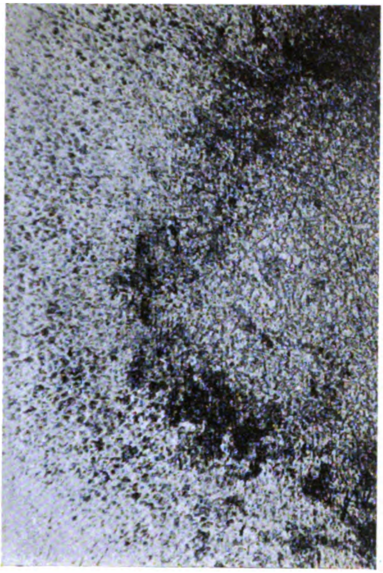

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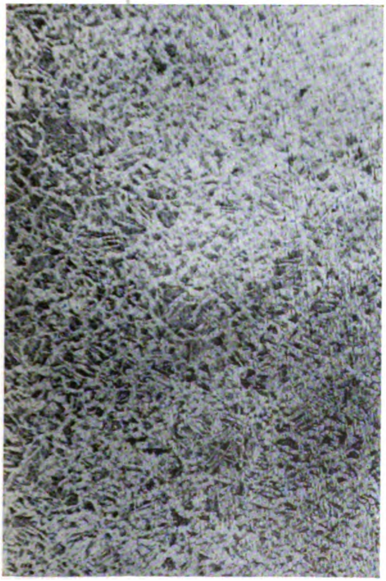

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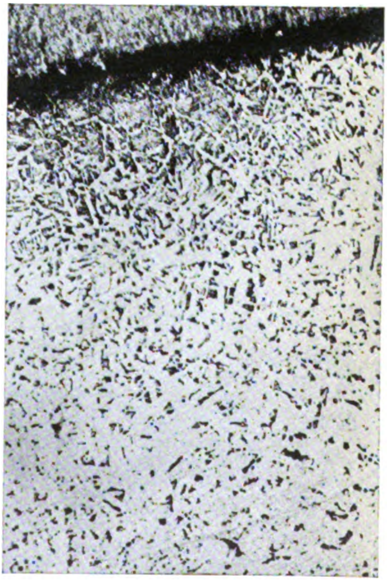

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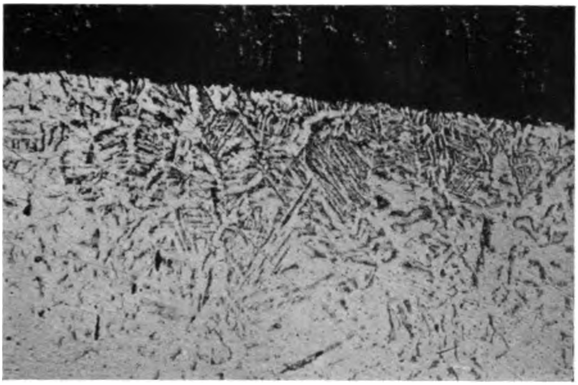
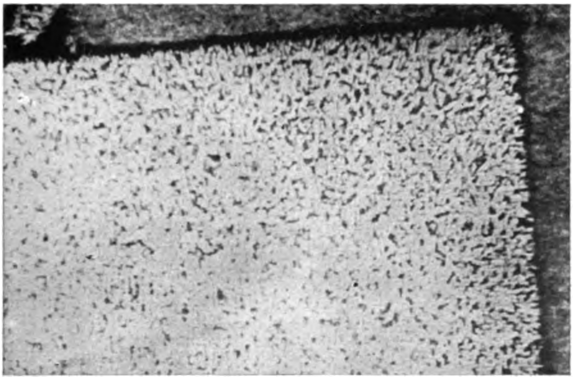


No. 9.



No. 10.

contact resulted from this treatment, a fact which seems to be a further confirmation of the suggestion made in reference to Experiment 7.

Experiment 8.

The following experiment was conducted to ascertain whether, at temperatures between 900° to 1000° C., carbon will, in the absence of occluded gases, diffuse from a highly carburised region to one of lower saturation, both regions being in the same piece of iron. For this purpose the mild steel sample from Experiment 7 was used. This sample had already been heated *in vacuo* for fifteen hours between 900° to 1000° C., and so should contain only traces of occluded gas; also the central portion of its surface was highly carburised whilst the outer portions were practically free from carbon. This piece was heated *in vacuo* between 900° to 1000° C. for twenty-two hours. A comparison of photomicrographs 6 and 7 clearly indicates the uniform distribution of the carbon resulting from this treatment.

Experiment 9.

The results of recent investigations have shown that the actual contact of specimens, during cementation, is of great importance,[1] and that gases have a great influence in promoting the passage of carbon into iron.

In order to observe the effects of small quantities of carbon monoxide on the transference of carbon from a piece of high carbon steel to one of lower carbon content, the following experiment was conducted. A piece of steel containing 1·4 per cent. of carbon was placed in the porcelain tube along with a piece of steel containing 0·06 per cent. of carbon. The two samples were not in contact. Both had previously been carefully weighed. The tube was completely exhausted of air, and then filled with carbon monoxide which had been dried and purified before admission by being passed through strong potash solution, alkaline pyrogallol, strong sulphuric acid, and finally over solid potash and calcium chloride. The porcelain tube was then completely exhausted of the gas, and five cubic centimetres of carbon monoxide admitted. The two specimens were then heated in this rarefied atmosphere for fifteen hours at 900° C. On reweighing the samples, it was found that their combined weights were unaltered; the other weights were as follows:—

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[1] L. Guillet and C. Griffiths, *Comptes Rendus*, 1909, vol. cxlix. p. 125.

	Grammes.
Mild steel piece, weight after above treatment	37·2430
,, original weight	37·2092
Increase	0·0338

	Grammes.
High carbon steel piece, weight before treatment	32·0910
,, ,, weight after treatment	32·0566
Decrease	0·0344

On determining the respective percentages of carbon in the two pieces, it was observed that 95 per cent. of the increase in weight of the mild steel was due to carbon and that the original percentage of carbon in the high carbon steel had diminished by an amount equivalent to that gained by the low carbon piece.

So much controversy has turned on the cementation of iron *in vacuo*, even by solid carbon, at temperatures below the melting point of the iron, that at present it would be unsatisfactory to draw conclusions other than those indicated by the preceding experiments. These conclusions are summarised as follows:—

1. Iron and steel, when heated *in vacuo* between 900° to 1000° C., lose weight.

2. Samples of steel, white iron, and, to a lesser extent, grey cast iron, will weld together, when heated *in vacuo* within the temperature range of 900° to 1000° C., provided their surfaces are clean, and in perfect metallic contact. The amount of this welding or intercrystallisation thus taking place between two samples of iron or steel is not dependent on the quantity of carbon present in them, or on the difference of carbon content of the two specimens, but only on the perfection of contact between their respective surfaces.

3. When welding occurs between two specimens of iron of unequal carbon content, the transference of carbon, by consequent diffusion from the high carbon steel to the steel of lower carbon content, is much more rapid than the trans-

ference of carbon effected by the agency of a gaseous vehicle such as carbon monoxide.

4. There can be no tendency to equalisation of carbon, by diffusion, between two samples of steel of varying carbon content, when they are heated together *in vacuo* between 900° to 1000° C. unless their respective surfaces are in perfect metallic contact, in which case welding results, and thus prevents any further investigation on the lines indicated by the results of Mr. Royston's experiment.

The following is a list of photomicrographs illustrating the results of the experiments.

The cross-sections through the welded portions of specimens were backed with fusible metal to facilitate the examination of their extreme edges.

1. Dead-mild steel used in the experiments. Etched with picric acid. × 100.
2. Fractured weld of flat Swedish iron specimen, heated *in vacuo* for twelve hours at 900° to 1000° C., in contact with a similar piece of steel containing 1·4 per cent. of carbon. × 20.
3. Cross-section through weld of same Swedish iron specimen showing carburised portion. Etched with picric acid. × 20.
4. Cross-section through weld of 1·4 per cent. carbon steel showing corresponding decarburised portion. Etched with picric acid. × 20.
5. Fractured welds of the five duplicate specimens heated in contact *in vacuo* for sixteen hours at 900° to 1000° C. Actual size.
6. Surface of weld of mild steel after being heated in contact with white iron *in vacuo* for fifteen hours at 900° to 1000° C. Etched with picric acid. × 20. Only half the welded area is shown.
7. The cemented portion (as shown in photomicrograph 6), after being heated for twenty-two hours *in vacuo* at 900° to 1000° C. Etched with picric acid. × 20.
8. Cross-section through one weld of mild steel heated *in vacuo*, in contact with grey hæmatite iron for fifteen hours, at 900° to 1000° C. Etched with picric acid. × 20.

9. Cross-section through weld of Swedish iron specimen, heated *in vacuo,* in contact with a piece of 0·89 carbon steel, for sixteen hours at 900° to 1000° C. Etched with picric acid. × 20.

10. Mild steel, carburised by means of carbon monoxide as described in Experiment 9. Etched with picric acid. × 20.

In conclusion the author acknowledges, with gratitude, the facilities and advice given by Professor Turner in carrying out the experiments; and also wishes to thank Messrs. O. F. Hudson and H. I. Coe for their suggestions and kind assistance throughout the work.

CORRESPONDENCE.

Dr. **Cecil H. Desch** (Glasgow) wrote that the necessity of very perfect contact between the two pieces of metal in any experiments on diffusion in the solid state had been clearly demonstrated in 1894 by W. Spring, who found that accurately faced specimens, free from grease, adhered perfectly, allowing diffusion to take place, but that slight inequalities of surface, or traces of impurity, prevented adhesion and consequently also diffusion. He (Dr. Desch) had often had occasion to confirm that conclusion. The flatness of surface required was equal to that of optically worked glass, and perfect cleanliness was essential. With ordinary flat surfaces one obtained local adhesion, as shown in Mr. Adams' plates. As a quantitative interpretation of such results was out of the question, it would seem to be worth while to repeat the experiments, using accurately plane surfaces, prepared without the use of any oily substance. The writer had been engaged on experiments of that kind with non-ferrous metals and alloys for several years past.

On the whole, it would seem that Mr. Adams' results were in agreement with those obtained by Profs. Arnold and McWilliam, to which allusion had been made in the paper.

Dr. J. E. **Stead**, F.R.S. (Middlesbrough), Vice-President, wrote that the results of Mr. Adams' research proved beyond doubt that, unless the metals were primarily crystallised together, there could be no diffusion of carbon from the metal rich in carbon to that containing little or none. It yet remained to be proved (1) whether it were carbon *per se*, carbide of iron, or the eutectoid that diffused; and (2) whether there was interdiffusion of the carbon carbide or of the eutectoid and the ferrite.

Professor T. **Turner** (Birmingham) wrote bearing testimony to the care and skill which had been shown by Mr. Adams in the conduct of his research, which had already been, in the hands of others, without satisfactory result, before Mr. Adams took up the work and brought it to a satisfactory conclusion. In the original experiment made by Mr. Royston, the samples which were heated in a vacuum did not show any loss in weight, and when carbon passed from one to the other the gain in weight of the pieces of low carbon steel was equal to the carbon lost by the other specimen. It was conceivable that carbon might exist at a temperature of 900° to 1000° C. in the free state, merely dissolved in the iron. In that case, if the carbon diffused into another piece of steel, the loss in weight of the one piece should equal the gain in weight of the other, as carbon, and carbon only, would diffuse. But if at that relatively high temperature the carbon in the steel were still combined with part of the iron to form the definite carbide Fe_3C, as was the case at lower temperatures, the result would be strikingly different. Since 12 parts of carbon combined with 168 parts by weight of iron to form that carbide, the diffusion of 12 parts of carbon would necessitate a total loss of 180 parts. In other words, the loss in weight of the high carbon steel should not be equal to the weight of the carbon lost, but 15 times that amount. If the carbon existed in a state of combination as some other carbide, such as Fe_2C or FeC, the loss of weight would still be much greater than that of the carbon alone, though not to the extent of 15 times. On the other hand, if the carbide $Fe_{24}C$ be assumed, then, on diffusing, one part of carbon should carry with itself no less than 112 parts of iron.

At first sight, therefore, the inquiry appeared to be a fascinating one, and moreover one likely to yield important and definite results. Unfortunately those hopes had not been realised. Mr. Adams had shown that if a reasonably good vacuum were maintained, steel did appreciably lose weight at 1000° C. He had also found that under such conditions no diffusion of carbon took place between high carbon steel and low carbon steel unless actual metallic contact were established. He had further found that if metallic contact were obtained intercrystallisation took place, and the specimens were so united that no separated portions, suitable for weighing, could be obtained. The result of Royston's experiment had still to be considered. The most probable explanation was that the vacuum produced was not sufficiently perfect, and that the gases evolved on heating the steel might have remained, in part at least, in the tube. If it were assumed that a very small quantity of carbon monoxide were left in the tube the transfer of carbon, by that means, would follow, and the gain of weight of one sample would be equal to the loss of the other. The original experiment was performed under the direction of the late Mr. MacMillan, while he (Professor Turner) was away from Birmingham, so that details were not available. Modern pumps and pressure gauges were not then to be found in metallurgical laboratories. The inconclusive character of that particular experiment was no reflection upon the general character of the work of so good an experimenter as Mr. Royston proved himself to have been.

Mr. **Adams** in reply expressed his thanks for the various contributions to his paper. He particularly wished to thank Dr. Stead for the kindly interest he had taken in the first paper presented by him (Mr. Adams) to the Iron and Steel Institute. In reply to Dr. Desch, he would be glad if Dr. Desch would give him some suggestions in regard to the preparation of accurately plane surfaces, and also tell him what method he would advise for standardising the contact between any two pairs of specimens.

SUPPLEMENTARY NOTES ON THE FORMS IN WHICH SULPHIDES MAY EXIST IN STEEL INGOTS.

By J. O. ARNOLD, D.Met., F.R.S. (Professor in Metallurgy)
and
G. R. BOLSOVER (Associate in Metallurgy)
of the University of Sheffield.

In a paper on this subject, published in the Journal of the Institute last year,[1] the authors remarked:—

> "It is a remarkable fact that the casts exhibiting more or less well-marked areas of the eutectic mixture all contained aluminium, whilst those presenting no evidence of a eutectic contained no aluminium. These facts suggest that the very small amount of aluminium present plays some part either in forming the eutectic or in preserving the pattern of the fallen-out manganese sulphide by checking its segregation into relatively large masses."[2]

The present paper contains the results of experiments made to decide definitely, if possible, the accuracy or otherwise of the authors' suggestions above quoted.

About 12 lbs. of crucible cast, No. 1499, weighing about 48 lbs., was, without any addition of aluminium, poured into an iron mould 1¾-inch square. The remaining 36 lbs. was, in a fluid state in the crucible, put back into the furnace, and allowed to cool in a lump overnight. Thus were obtained portions of identical steel quickly and slowly cooled. Drillings were taken near the top of the ingot and near the top and bottom of the lump, and on analysis registered the following figures per cent.:—

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[1] *Journal of the Iron and Steel Institute*, 1914, No. I. pp. 396 *et seq.*

[2] *Op. cit.*, p. 403.

Cast No. 1499.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Aluminium per Cent.
Ingot (near top) . .	0·26	0·075	1·11	0·517	0·021	Absent
Top of lump . .	0·26	0·084	1·07	0·534	0·021	
Bottom of lump . .	0·20	0·056	0·76	0·302	0·017	

The main segregations noted in the lump are 0·23 per cent. sulphur and 0·31 per cent. manganese. Both these segregations are doubtless largely due to a common cause, namely, the rising towards the top of the lump of MnS.

An ingot, No. 1461, which had been cast 1¾-inch square, after the addition of about 0·03 per cent. of pure metallic aluminium, was analysed for segregation on drillings taken from both the top and the bottom of the ingot. The following percentages were registered:—

Ingot No.	Size.	Position.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Aluminium per Cent.
1461	1¾ in. sq.	top	0·27	0·167	0·74	0·424	0·019	trace
1461	1¾ in. sq.	bottom	0·28	0·158	0·78	0·478	0·018	trace

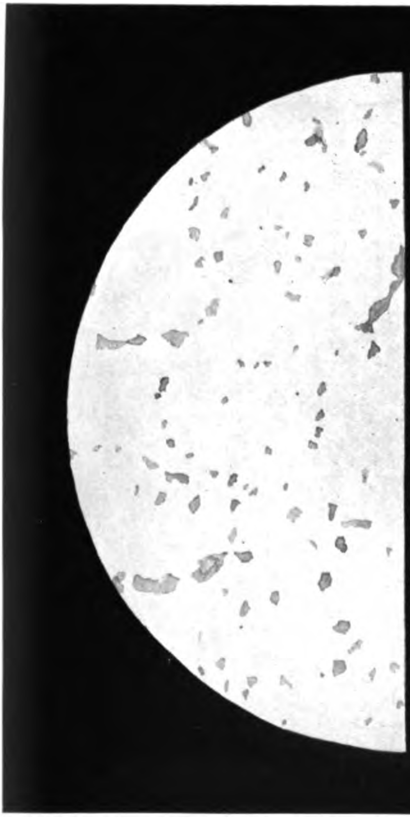
The above figures show that the aluminium has practically prevented any segregation. This curious and unexplained action of aluminium was, at the meeting of the Institute at Sheffield in 1905, proved by Mr. B. Talbot in an exhaustive and most valuable paper on "Segregation in Steel Ingots."[1]

The amount of aluminium employed by Mr. Talbot was very small, amounting to only about 0·007 per cent. per ingot.

MICROSTRUCTURE OF INGOT AND LUMP FROM CAST No. 1499.

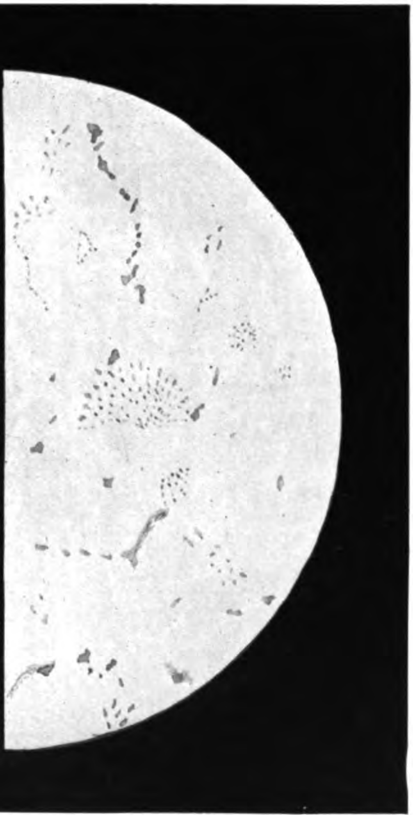
Micrograph No. 1 (Plate XLIII.) shows the structure of ingot 1499, so far as sulphides are concerned. The MnS is distributed in irregular sectional patches of a dove-grey colour. With these, and often in juxtaposition, are a limited number

[1] *Journal of the Iron and Steel Institute*, 1905, No. II. p. 204 *et seq.*



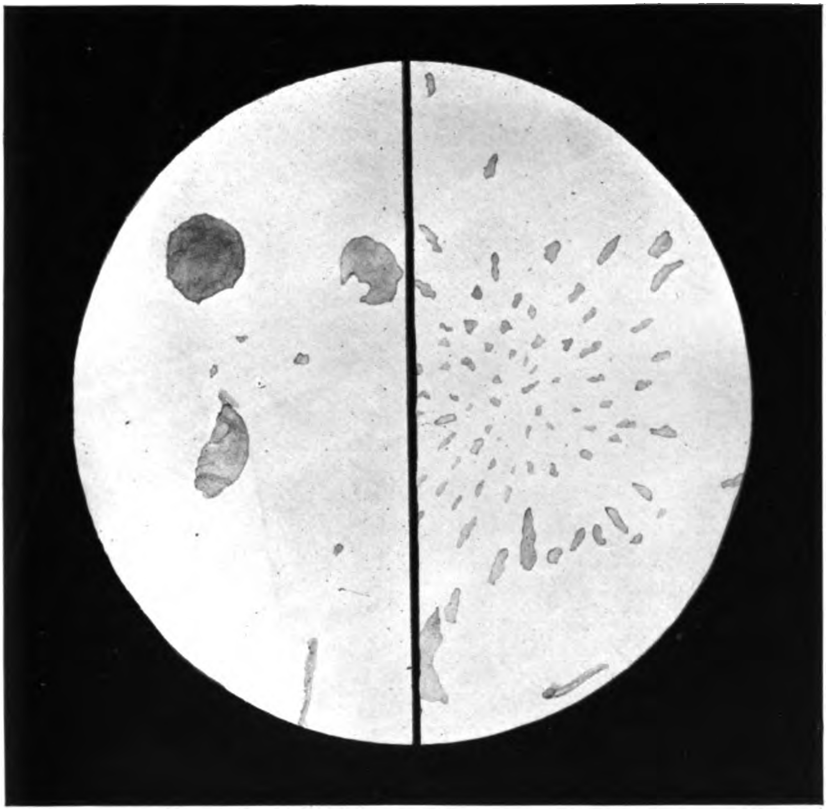
MICROGRAPH No. 1. Ingot 1499.

Sulphur . . . 0·517 per cent.
Manganese . . . 1·11 ,,
Without Aluminium. Quickly cooled.
Magnified 450 diameters, and reduced one-half in reproduction. Unetched.



MICROGRAPH No. 2. Ingot 1540.

Sulphur . . . . 0·493 per cent.
Manganese . . . 1·02 ,,
With Aluminium. Quickly cooled.
Magnified 450 diameters, and reduced one-half in reproduction. Unetched.



MICROGRAPH NO. 3. Lump 1499.

Sulphur . . . . . 0·302 per cent.
Manganese . . . . 0·76 ,,

Without Aluminium. Slowly cooled.

Magnified 450 diameters, and reduced one-half in reproduction. Unetched.

MICROGRAPH NO. 4. Lump 1540.

Sulphur . . . . 0·480 per cent.
Manganese . . . . 1·02 ,,

With Aluminium. Slowly cooled.

Magnified 450 diameters, and reduced one-half in reproduction. Unetched.

of smaller patches of pale brown FeS. Micrograph No. 3 (Plate XLIV.) shows the segregation under the influence of slow cooling of the MnS into relatively huge rounded masses. With one of these clear-cut areas of FeS are juxtaposed, whilst an isolated elongated streak of FeS is also present. These two sulphides, when present together under steel-making conditions, so far as the authors' experience goes, never interpenetrate to form a solid eutectic solution or double sulphide, but are always sharply segregated.

ADDITIONAL EXPERIMENTS.

Crucible cast No. 1540, weighing about 48 lbs., was poured, as to 9 lbs., into a 1¾-inch square ingot, whilst the remaining 39 lbs. was returned in the crucible to the furnace, and allowed to cool overnight. To this cast about 0·05 per cent. of metallic aluminium was added five minutes before teeming the small ingot. The composition per cent. of this ingot, and also of the top and bottom of the lump, are set forth in the following analyses:—

Cast No. 1540.[1]	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Aluminium per Cent.
Top of ingot . .	0·3	0·163	1·02	0·493	0·02	0·01
Top of lump . .	0·3	0·163	1·02	0·493	0·021	0·01
Bottom of lump. .	0·26	0·187	1·02	0·480	0·021	0·01

The aluminium has virtually prevented any segregation in the very slowly-cooled lump, whereas such segregation with reference to carbon, sulphur, and manganese was well marked in the non-aluminium lump of cast 1499.

MICROGRAPHIC STRUCTURE OF CAST NO. 1540.

Ingot 1540 presented the structure shown in micrograph No. 2. There are irregular sectional patches of dove-grey MnS, and a few streaks of pale brown FeS, in which pieces of MnS are embedded. But the most remarkable features are areas showing the eutectic structure of a decomposed solid solution or compound (xFe, yMnS) described in the authors' first paper already referred to. The aluminium has, by largely checking the segregation of the minute particles of MnS into comparatively large masses, preserved very clearly one large and several small areas of the eutectic mixture (xFe + MnS). The term eutectic as here applied, if convenient, is almost certainly inaccurate, because this word has common reference to the "constituent last fluid," but the present constituent, from facts in the authors' possession, is probably the constituent first to freeze, say at a temperature of 1450° C. Micrograph No. 4 shows, in the slowly-cooled alloy, this so-called eutectic structure on a relatively huge scale, and areas of this type occur frequently throughout the microsection, being surrounded by regions of ferrite (and pearlite) relatively free from sulphides.

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[1] The remarkably similar figures registered for the tops of the ingot and lump are the means of duplicate analyses very carefully made.

The structure of No. 4, it will be noted, consists almost entirely of large and smaller nodules of MnS. A single streak of FeS is also present, and in one end of this there is embedded a little nodule of MnS. The contrast of the segregation of MnS in micrographs Nos. 3 and 4 is remarkable, and constitutes additional testimony to the power of aluminium in checking sulphide segregations.

Composition of the definite Solid Solution or Compound (xFe, yMnS).—There is no method of readily determining this composition. An inspection of the structure (xFe + yMnS) suggests the presence of roughly about 12 per cent. MnS, corresponding say to the formula (12Fe + MnS). But it is well to exercise the greatest caution in judging quantitative compositions from a single plane of microsection. A striking example of this is Sorby's estimate, made micrographically, that his pearly constituent contained about 33 per cent. of iron carbide, whereas subsequent investigations by other methods showed that the actual percentage of Fe_3C present was only 13 per cent.

NOTE.

The magnifications stated below the micrographs have reference to the original 6-inch circles in which the structures were micrometrically and orthochromatically reproduced, subject to the reductions stated.

CORRESPONDENCE.

Mr. **Ralph G. Scott** (London) wrote that the paper contained much interesting data relative to the addition of aluminium to molten steel and corroborated the experiments of Mr. Talbot. He thought the information would have been more useful and complete if the author had given analyses from the bottom of the ingots in both cases (Casts 1499 and 1540) as well as from the top, for after all it was with ingots steel-makers had to deal, and it would have been particularly interesting to learn if there was a noticeable difference in segregation produced by the addition of aluminium in the case of such small ingots.

If he (Mr. Scott) were not mistaken, Dr. Stead mentioned in connection with the examination of "bears" in blast-furnaces that he had obtained some of the "dove-coloured" manganese sulphide, so called, in a massive form. On examining it he found that it was not pure sulphide but a mixture of sulphides of manganese and iron. He (Mr. Scott) wished to ask whether that statement might not tend to modify the conclusion drawn by the authors with regard to the dove-coloured spots on the micro-sections being taken always as pure manganese sulphide.

RESEARCHES ON THE IRON, SILICON, AND CARBON ALLOYS.

By GEORGES CHARPY (Montluçon) and ANDRÉ CORNU-THENARD.

The properties of the iron-carbon-silicon alloys, and, in particular, the transformations they undergo under the influence of variations in temperature, present peculiarities which do not appear to have been fully elucidated by the investigations hitherto carried out, and amongst which may be mentioned those of Sir Robert Hadfield, Guillet, Baker, and others. The authors have therefore conceived it useful to reinvestigate these transformations by taking into consideration successive series of metals containing varying amounts of silicon and carbon, and endeavouring both to co-ordinate and to confirm the results of thermal, chemical, and microscopic analysis.

On the other hand, this investigation appears to them to have shed some light on the iron-carbon system itself: by taking into consideration, so to speak, the continuity of the perturbations introduced by the progressive variation of an element it is possible to arrive, by extrapolation, at an understanding of what would occur in the complete absence of that element.

The work has been carried out on two main groups of alloys:—

(1) Steels, which have been divided into dead soft steels containing 0·10 to 0·15 per cent. of carbon (the silicon varying from 0·1 to 7 per cent.), and semi-hard steels containing 0·35 to 0·40 per cent. of carbon (the silicon varying from 0·1 to 4·5 per cent.).

(2) Cast iron with 2 per cent. of carbon (silicon varying from 0·1 to 7 per cent.).

A logical sequence of ideas led the authors to let the researches on these two groups of metals frequently overlap. Still, in order to simplify the account, they will give, in succession, the facts observed in each instance, and confine themselves subsequently to showing how the different results may be harmonised with each other.

I. CRITICAL POINTS IN ALLOYS ONLY SLIGHTLY CARBURISED.

The first series of metals tested comprised five alloys, corresponding with definite commercial qualities, the chemical compositions being as follows:—

No. of Sample.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.
9–4094	0·05 to 0·06	0·06	0·36	0·008	0·012
11–1011	0·14 to 0·14	0·26	0·38	0·007	0·016
12–6445	0·09 to 0·07	0·57	0·37	0·010	0·022
10–3442	0·06 to 0·07	2·50	0·28	0·011	0·010
12–6414	0·05 to 0·04	3·91	0·40	0·041	0·026

The investigation comprised, on the one hand, the cooling method with automatic recording, by means of a double Saladin-Le Chatelier galvanometer, and on the other the dilatation method, using the arrangement described in an earlier paper by Charpy and Grenet.[1]

The diagrams obtained on cooling are reproduced in Fig. 1. It will be seen that the first alloy clearly shows the three perturbations usually denominated A1, A2 and A3 ; the highest points of the corresponding bends occur at 650°, 720°, and 785° C. respectively.

An examination of the whole of the succeeding curves shows, in conformity with the results published by Osmond, Arnold, Stead, Baker and others, that the point A3 diminishes in intensity (while rising a little in the temperature scale) as the percentage of silicon increases, and that it disappears before that percentage reaches 2·5. The authors will show later on, with greater accuracy, what proportion of metalloid appears to lead to the disappearance of the A3 point.

The A2 point falls noticeably in proportion as the percentage of silicon increases, whereas, on the contrary, the A1 point rises, until the two points which, to begin with, are separated by an interval of 65°, become conjoined in the alloy 12–6414.

The dilatation curves which are shown in Fig. 2 show that the addition of silicon to iron does not appreciably affect the dilatation coefficient between 0° and 700° C. On the other hand, it is found that sample 12–6414, containing 3·9 per cent. of silicon, no longer reveals any dilatational anomaly; this shows that it is the A2 point that shows itself most, on

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[1] *Comptes Rendus des Seances de l'Académie des Sciences*, 1902, No. 1, p. 540.

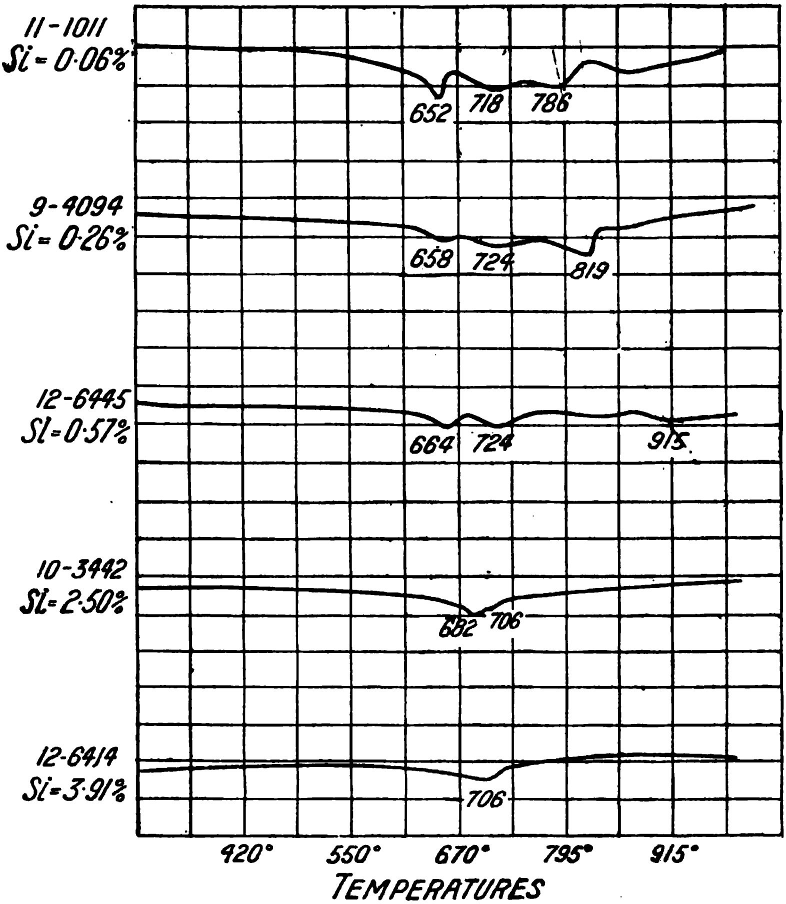

FIG. 1.—Ordinary Alloys containing less than 0·15 per cent. of Carbon and varying percentages of Silicon. Coolings recorded by the Double Galvanometer.

dilatation curves, in low carbon steels, and at the same time confirms the fact, already recorded by Charpy and Grenet,[1] namely that the point A2 does not correspond with any peculiarity in the dilatation diagram. It must not, however, be concluded, from this, that this point possesses no individuality of its own, and that it is only a residuum of the transformations

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[1] *Comptes Rendus*, 1902, No. 1, p. 598.

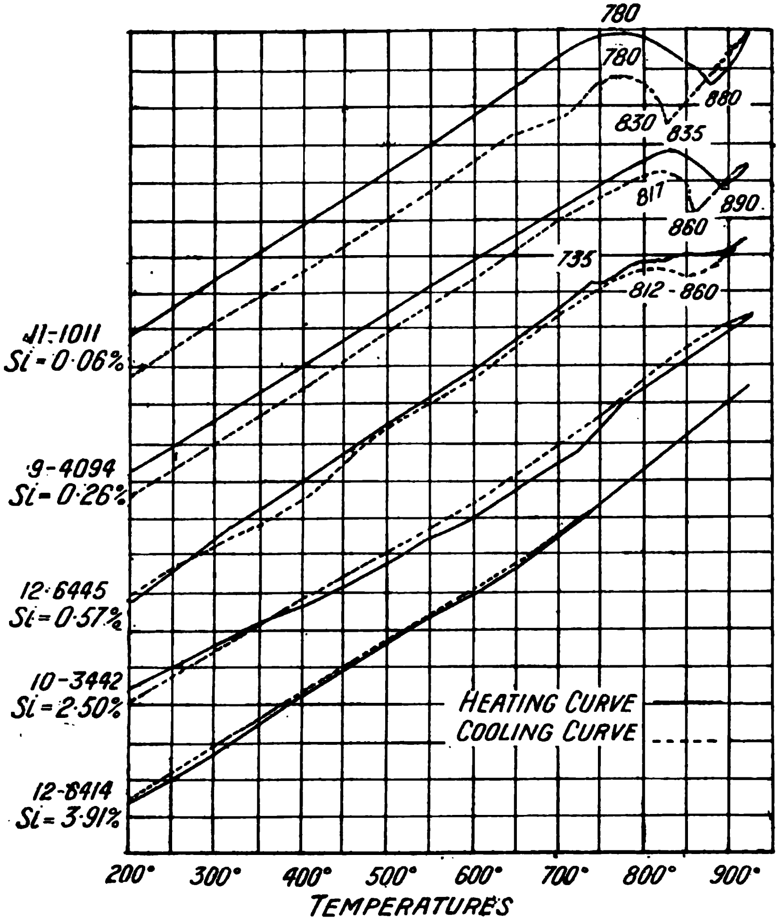

FIG. 2.—Ordinary Alloys containing less than 0·15 per cent. of Carbon and varying percentages of Silicon. Dilatations.

corresponding with the points A1 and A3. The authors will show that, on the contrary, it is possible to eliminate the A1 and A3 points, while at the same time preserving the A2 point.

Fig. 3 shows the dilatation and cooling curves of three

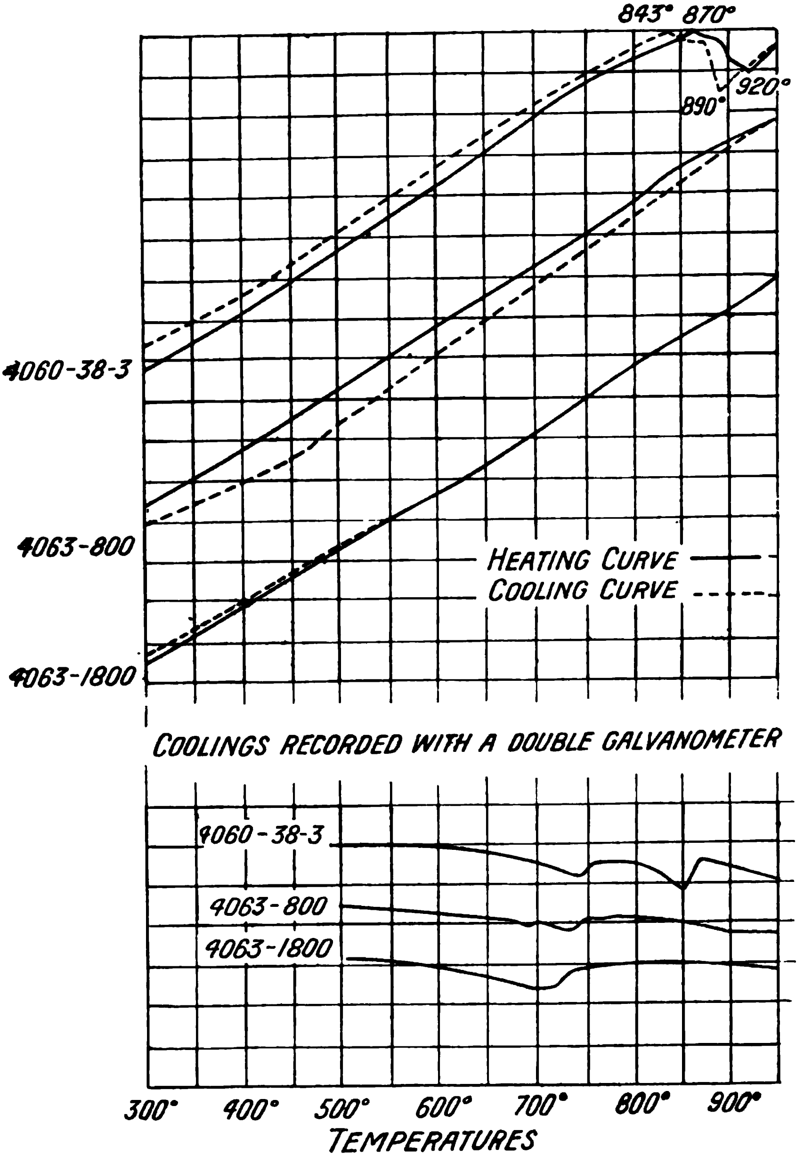

FIG. 3.—Ordinary Alloys containing less than 0·15 per cent. of Carbon and varying percentages of Silicon. Dilatations.

fresh steels obtained by the melting of Swedish iron in a crucible, with the addition of suitable quantities of ferro-silicon. In these alloys, the sample numbers and chemical composition of which are given below, every effort was made to reduce the proportion of carbon to a minimum, and to keep the silicon between 0·10 and 2 per cent.

Sample No.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.
4060–38–3	0·03–0·04	0·10	0·06	0·013	0·010
4063–800	0·06–0·07	1·13	0·06	0·014	0·010
4063–1800	0·04–0·05	2·13	0·05	0·017	0·006

It will be seen that in the case of the sample 4063–800 (silicon 1·13 per cent.), the point A3 is almost entirely suppressed. From further dilatometric experiments, details of which are omitted in order to avoid unduly lengthening the present paper, it may be concluded that the point A3 is entirely suppressed as soon as the proportion of silicon in the alloy reaches 1·30 per cent.

On a further inspection of Fig. 9 it will be seen that the A1 point does not appear, on cooling, when the proportion of carbon in the metal is 0·04 per cent. or less. The curve of the sample 4060–38–3 may, therefore, be regarded as approximating closely to the diagram of pure iron.

Experiments carried out on a sample of electrolytic iron have enabled the authors to locate the point A2 of the metal, on cooling, at about 730°, and the point A3 at about 875°.

Finally, in order further to confirm their conclusions, the authors have tested a third series of metals prepared with very special precautions for securing their purity, and with a further range of silicon percentages. This fresh series, which comprises seven alloys obtained by melting a Swedish iron with increasing increments of ferro-silicon in a crucible, has been examined only by the thermal method. The table below shows the separate sample numbers, and the average chemical composition of these metals:—

Sample No.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.
4207–31	0·15	0·11	<0·08	<0·010	<0·010
4209–25	0·15	1·02			
4223–26	0·12	1·80			
4210–27	0·15	3·16			
4210–28	0·15	4·00			
4211–29	0·15	5·87			
4211–30	0·11	6·10			

The diagrams obtained have been plotted in Figs. 4 and 5. The curves in Fig. 4 comprise only the coolings carried out from 900°, at a rate such that the temperature fell from 950° to 150° in two hours. The heating up to 900° occupied about twenty minutes. The curves of Fig. 5 comprise heating and cooling for four samples of the series, chosen as being most representative. The heating, starting from the normal temperature to 1200°, lasted two hours, on an average; cooling from 1200° to 450° occupied 3½ hours. It is advisable to take into consideration this question of rates; thermal perturbations may, as a matter of fact, cause notable displacements on the temperature scale, according to whether the operation be carried out quickly or slowly. This fact is easily explained when it is recalled that the different transformations do not involve the occurrence of the same periods of lag, or that, in other words, certain critical points are almost reversible and others are decidedly irreversible.

Take, first of all, Fig. 4. We find once again, on the curve relating to the first alloy, the three anomalies characteristic of dead soft steels, the peaks of the bends corresponding to 660° (A1), 740° (A2), and 820° (A3) respectively.

On the other hand, a comparative examination of the earliest curves confirms the previous observations to which the less pure metals had given rise; when the silicon persentage increases, the A2 point falls and the A1 point rises, co that the two points, originally 80° apart (Alloy No. 1) are mutually blended in the alloy 4210–27 (silicon 3·16 per cent.).

In metal 4210–28 (silicon 4 per cent.) we find, once again, two distinct points: subsequently the upper point disappears in the richer alloys, and the latter present but a single anomaly, the temperature of occurrence of which steadily falls.

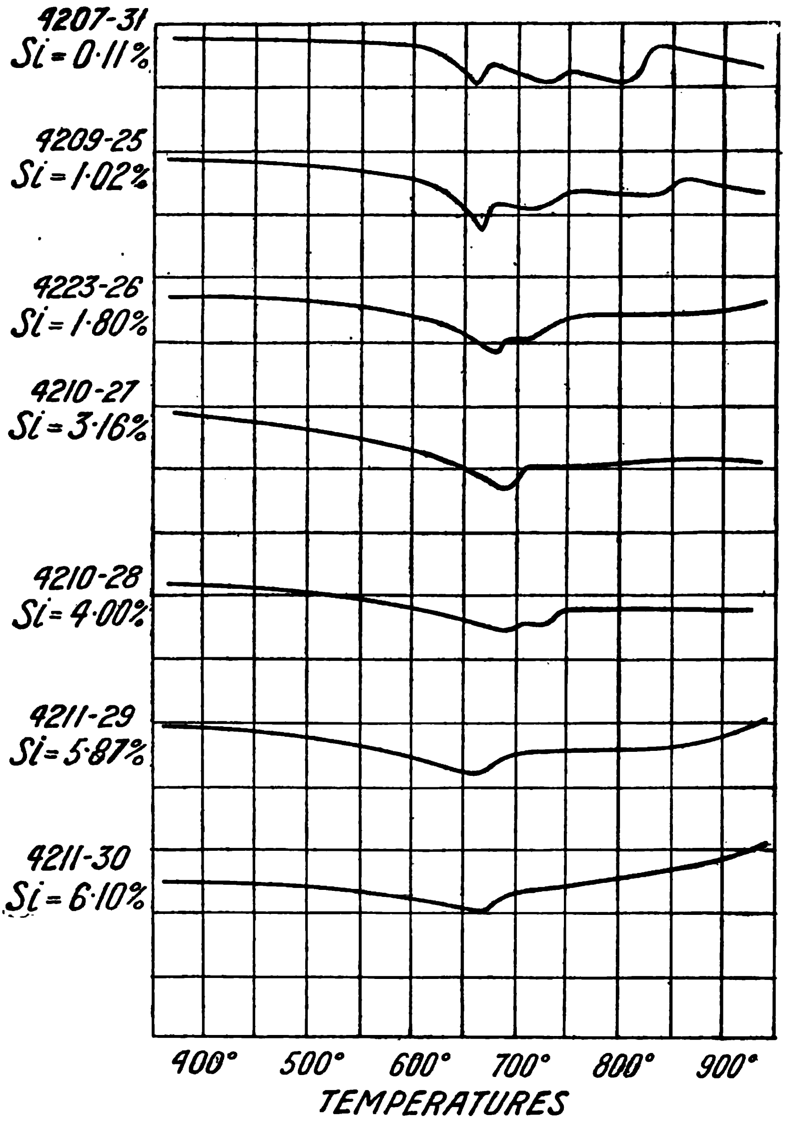

FIG. 4.—Ordinary Alloys containing less than 0·15 per cent. of Carbon and varying percentages of Silicon.

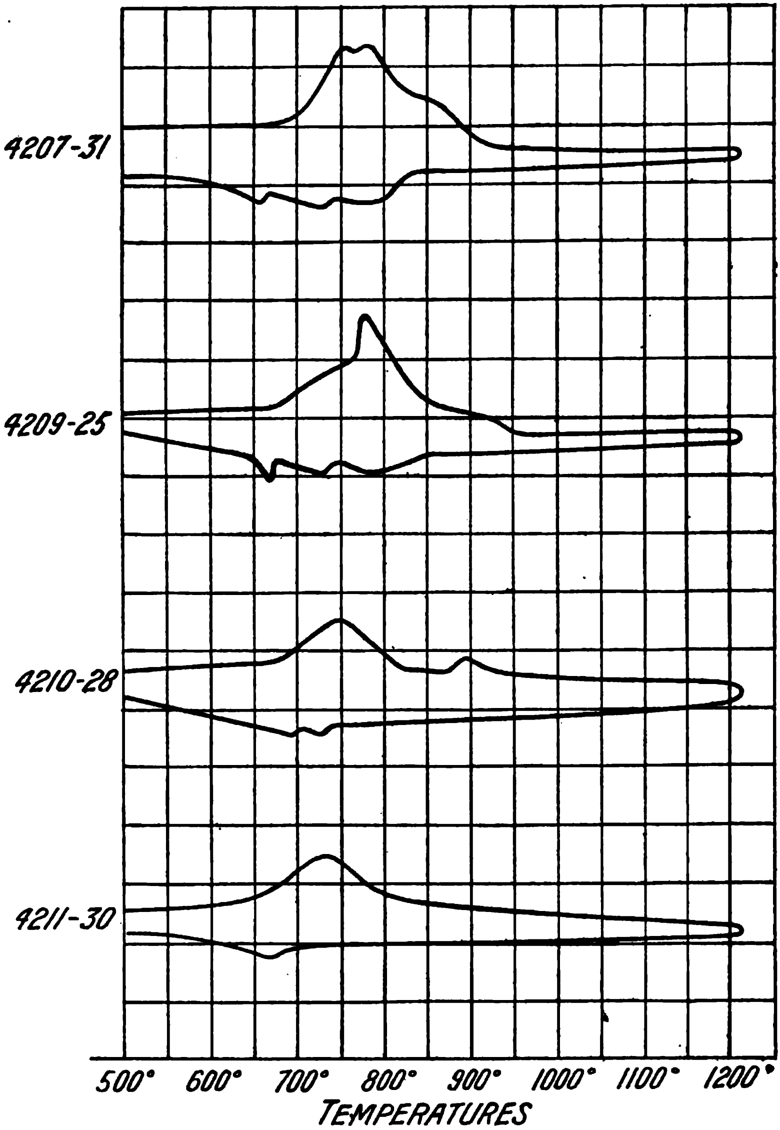

FIG. 5.—Ordinary Alloys containing less than 0·15 per cent. of Carbon and varying percentages of Silicon.

The diagrams of Fig. 5 allow of the phenomena being more readily followed, for the points A1 and A2 have, on heating, a still more characteristic appearance than they have on cooling. The normal A1 point occurs as a sharp and tapered point, whereas the A2 point spreads out over a wider temperature zone, and presents a less sudden rise.

If, therefore, only the heating curves be considered, it is found, as regards curve 4207–31 (silicon 0·11 per cent.) that the point A1 occurs at about 755°, and hardly has its climax been passed than the A2 point shows itself, and becomes manifest at 780°; the A3 point only shows as a slight wave in the curve. In sample 4209–25 (silicon 1·02 per cent.) the A1 point begins to appear before the A2 point has reached its culmination; the two anomalies thus appear to have been reversed. When metal 4210–28 (silicon 4 per cent.) is in question the occurrences are clearly distinct; the A2 point located at about 750°, and the A1 point, greatly diminished, located at about 890°. In the last sample the A2 point alone occurs, at 730°.

An attentive examination of the appearance of each of these perturbations has led the authors to the conclusion that the displacement of the A1 and A2 points takes place, in both instances, always in the same direction; that at a certain rate of cooling they became merged in the metal containing 3·16 per cent. of silicon, and that they became inverted in the alloy containing 4 per cent. of silicon. Finally, the solitary point encountered in alloys rich in silicon certainly seems to be the A2 point, which persists after the gradual disappearance of the A1 point.

These results have been confirmed by more accurate and more direct experiments, to be described in the course of this paper. They have been based on the chemical and micrographical examination of the samples.

II. CRITICAL POINTS IN THE ALLOYS CONTAINING 0·35 TO 0·40 PER CENT. OF CARBON.

An investigation of these alloys was carried out concurrently with the preceding researches. The three metals experimented with and prepared in the crucible had the following chemical composition:—

	Sample.		
	No. 4081—I.	No. 4081—II.	No. 4081—III.
	Per Cent.	Per Cent.	Per Cent.
Carbon	0·35–0·40	0·35–0·40	0·35–040
Silicon	0·36	2·27	4·21
Manganese	0·89	0·89	0·87
Phosphorus	<0·025	<0·025	<0·025
Sulphur	<0·020	<0·020	<0·020

The authors have confined themselves to reproducing the dilatation curves (Fig. 6) and the cooling curves (Fig. 7), pointing out that the predominating perturbation loses a good deal of its intensity in passing from the metal 4081–I (0·36 per cent. of silicon) to metal 4081–III (with 4·21 per cent. of silicon), owing to the elimination of point A3, to the separation of the A1 and A2 points, and the gradual disappearance of the A1 point. On the cooling curve of the alloy 4081–III, in particular, the A2 point, situated at about 670°, is sharply distinguished from the A1 point, which occurs at 714°.

It is unnecessary to pursue the investigation further to recognise that, had percentages of silicon in the neighbourhood of 6 per cent. been attained to, the A2 point alone would have persisted in the curves (see pages 292 and 293).

III. THE PRECIPITATION OF GRAPHITE IN DEAD SOFT AND MEDIUM HARD SILICON STEELS.

With what modification in the structure of the steel does the gradual diminution and ultimate disappearance of the A1 point correspond?

The microscope yields direct information on this question by showing that, with the very highly siliconised alloys, and as long as the cooling is not effected too suddenly, the carbon is present in the state of graphite. The perturbation corresponding with the formation of pearlite does not, therefore, intervene in this instance, whence we have the ultimate disappearance of the A1 point.

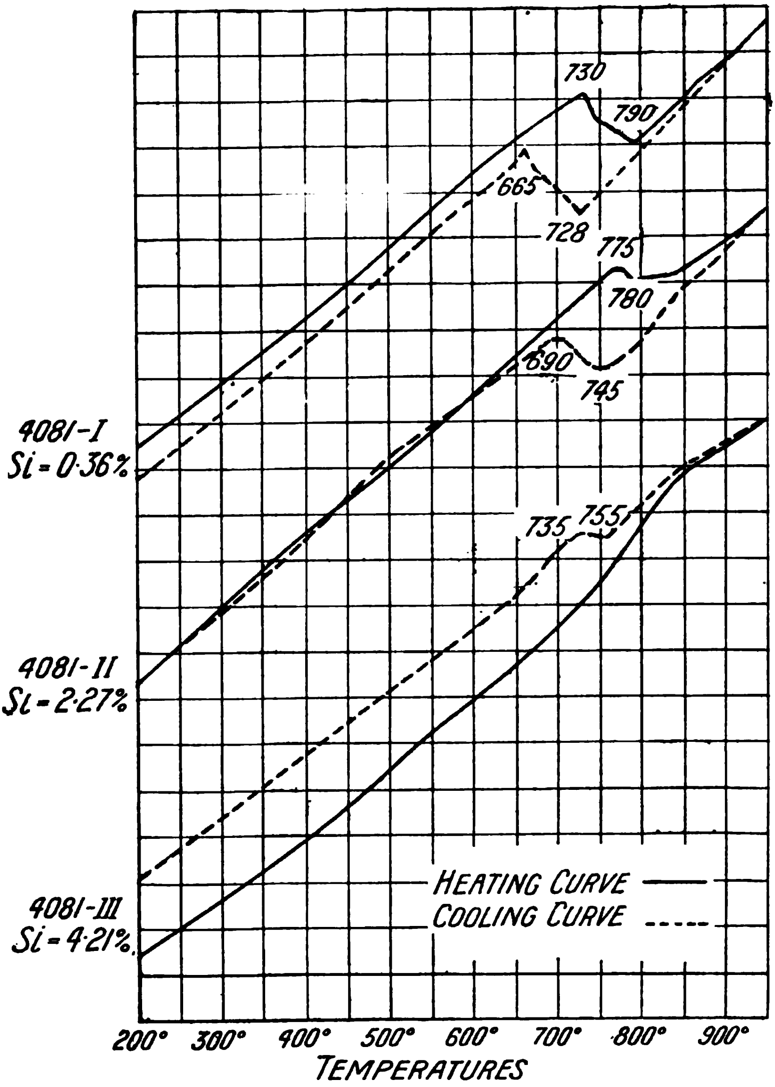

FIG. 6.—Alloys containing 0·35 to 0·40 per cent. of Carbon and varying percentages of Silicon. Dilatations.

The argument may, however, be carried further: experiment has shown that the carbon may be wholly precipitated in the graphitic state in forged steels with low or medium carbon contents, provided that the silicon content exceeds 3 per cent., that the annealing be carried out at a temperature above 750° C., but below a certain limit, which is a function of the percentage of total carbon; and finally, that the rate of cooling after the annealing be very low.

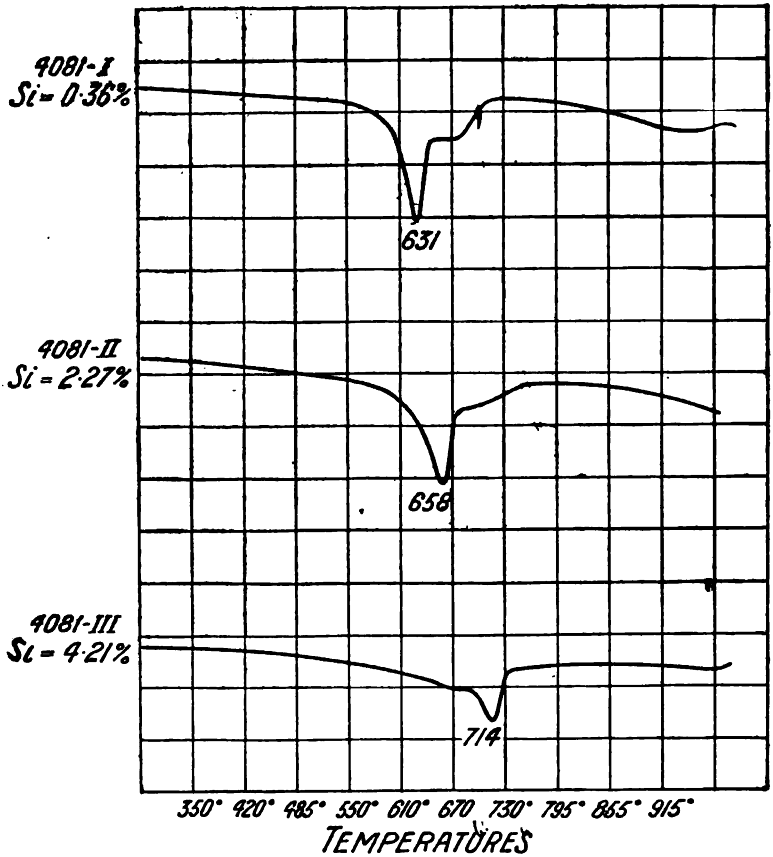

FIG. 7.—Alloys containing 0·35 to 0·40 per cent. of Carbon and varying percentages of Silicon. Cooling curve registered with the Double Galvanometer.

Below are given, as an example, the results obtained on a mild silicon steel of the type frequently employed at the present day for the manufacture of steels intended for the construction of electric dynamos and of transformers. The composition of that steel, which the authors have designated Mark 3871–2, was as follows:—

	Per Cent.
Carbon	0·14 to 0·15
Silicon	3·9
Manganese	0·35
Phosphorus	0·03
Sulphur	0·018

The table given below shows the proportions of graphite in this metal after different annealings. The determinations were made by ordinary methods of chemical analysis, by separating the graphite, by dissolving the alloy in the form of drillings in nitric acid of specific gravity of 1·8 at boiling temperature:—

Annealing Temperatures, Degrees C.	Duration of Annealing.	Mode of Cooling.	Proportion of Graphite per Cent.
700	1 hour	Slow (5° per min.)	0·00
750	1 ,,	,, ,,	0·08
800	1 ,,	,, ,,	0·13
800	3 hours	,, ,,	0·14
800	10 ,,	,, ,,	0·14
800	1 hour	Air cooled	0·11
850	1 ,,	Slow	0·01
900	1 ,,	,,	0·00

The authors have carried out several series of experiments of the same description on various samples containing more or less carbon and proportions of silicon ranging between 3 and 4 per cent. The results have remained constant, but as soon as the percentage of silicon falls between 2 and 2·5 it is no longer possible to cause the precipitation of the graphite, no matter what the temperature or period of annealing may be. They wish, nevertheless, to emphasize the point that the rate of the formation of the graphite is infinitely more rapid in the wrought steels in comparison with what occurs in the metals as cast. In the latter it appears to be exceedingly difficult to attain to the precipitation of the whole of the graphite.

Micrographic examination distinctly corroborates the conclusions to which the chemical analysis has led, and enables the investigation to be pushed still further.

In order to follow the action of annealing at different temperatures in a well-defined portion of metal, rods 1 square centimetre in section and 2·4 centimetres in length have been heated in a furnace of the same length, the temperatures in which varied progressively—from one end to the other—from 450° to 1100°. Thermo-electric couples gave the temperatures at intervals of 3 centimetres. After the heat treatment, which comprised the maintenance of the highest temperature over a period of two hours and very slow cooling, the rod was scraped along one of its surfaces to remove the layer of decarbonised metal, polished, etched, and examined under the microscope.

Plates XLV., XLVI., and XLVII. show a series of photographs obtained at different lengths along the same rod. The composition of the steels was as follows:—

	Plate XLV. (Steel 3871-2.)	Plate XLVI. (4081-II Crucible Steel.)	Plate XLVII. (Steel 4081-III Crucible Steel.)
	Per Cent.	Per Cent.	Per Cent.
Carbon . . .	0·14-0·15	0·35-0·40	0·35-0·40
Silicon . . .	3·9	2·2	4·2
Manganese . .	0·35	0·8	0·8
Phosphorus . .	0·030	0·023	0·025
Sulphur . . .	0·018	0·014	0·014

It was found that no matter what the temperature of annealing was, no graphite was formed in sample 4081–II, the percentage of silicon in which is below 3 per cent. There is readily seen to be, at about 725°, the commencement of the disintegration of the pearlite, but this disintegration does not continue, no matter how long the annealing be prolonged.

In regard to the steels 3871–2 (carbon 0·10 to 0·15 per cent.) and 4081–III (carbon 0·35 to 0·40 per cent.), the silicon content of which is in the neighbourhood of 4 per cent., the pearlite is seen to diminish gradually and to disappear entirely at about 800° C. in the first instance, and at about 850° C. in the second. The metal then shows nothing further, under the microscope, than an area of coarse grains of jointed ferrite. Subsequently the pearlite is again formed at a higher temperature and, at about 1000°, appears in large masses, which are present in far higher proportions than in non-silicon alloys containing the same amounts of carbon. This latter fact seems to indicate that the eutectoid mixture corresponds, in silicon' steels, with a carbon percentage of less than 0·8 per cent.

These different results agree perfectly with the previous observations made on ferro-silicons, if a circumstance which does not exist in the case of pig irons be taken into account, namely, that the metal is capable of dissolving increasing proportions of carbon with increasing temperatures. The separation of the graphite cannot, therefore, be observed so long as the temperature is sufficiently high for the whole of the carbon to be held in solution. The temperature range within which, for a given alloy, the formation of graphite can be observed, has then, as its lower limit, the temperature T at which the transformation of the cementite into graphite begins to take place and, as its upper limit, the temperature T′ at which the solubility of the graphite in the alloy corresponds with the total carbon percentage of the alloy. The temperature T falls when the percentage of silicon rises,[1] whereas T′ rises when the percentage of silicon rises, and also when the percentage of carbon rises. If T′ is lower than T (which occurs in alloys with very little carbon or silicon), the formation of graphite cannot be discerned. If, on the contrary, T′ is higher than T, the precipitation of graphite is observed within a range which is wider the higher the percentages of carbon and silicon present.

These different results being obtained, it remains to find out how this formation of graphite in the steels acts on their critical points.

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[1] Charpy and Grenet, "On the Equilibrium of Iron-carbon Systems," *Comptes Rendus*, 1902, vol. cxxxiv. p. 103.

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IV. CRITICAL POINTS IN STEELS CONTAINING 4 PER CENT. OF SILICON WHICH HAVE UNDERGONE GRAPHITIC TRANSFORMATION.

It is possible to fix very clearly the modifications undergone by the critical points of a steel, according to whether we start with an alloy having a pearlitic structure or with one having a graphitic structure. Fig. 8 shows the cooling curves, ascertained by the double galvanometer, of the metals 3871–II and 4081–III described above.

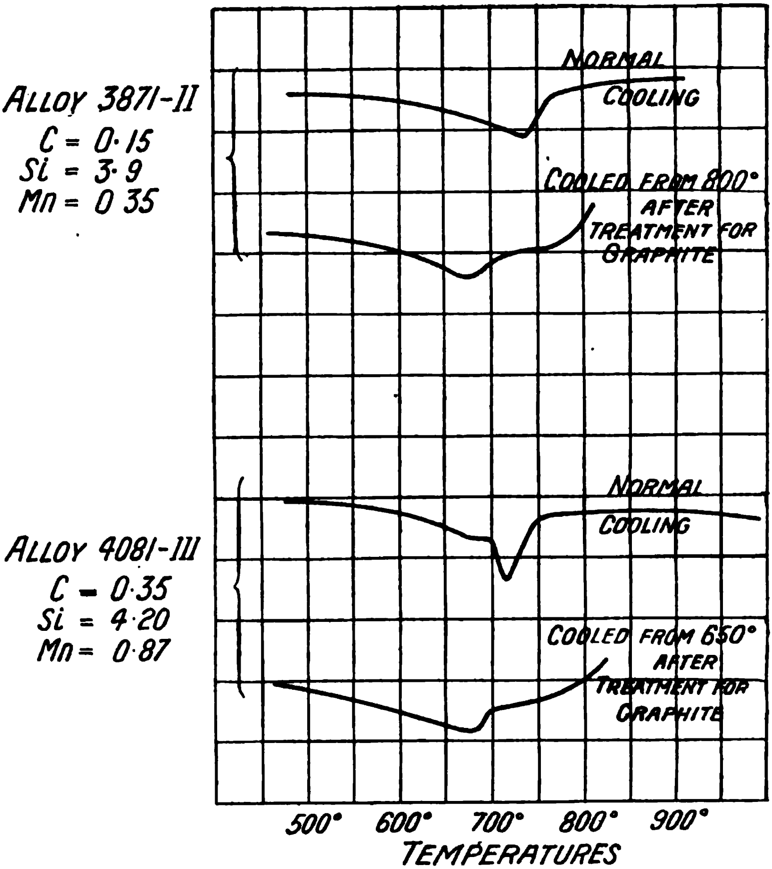

FIG. 8.—Cooling Curves recorded with a Double Galvanometer.

No. 1 (the upper curve) is taken after heating an unannealed sample at 950° C., that is to say, having a pearlitic structure.

No. 2 (the lower curve) is taken after heating a sample which has undergone a previous annealing at 800° (3871–II) or 850° (4081–III) for three hours, followed by very slow cooling, to 800° or 850°, that is to say, presenting a graphitic structure.

In both instances the rate of cooling from the initial temperature was, of course, the same.

It is found that, in both alloys, the A1 and A2 points coexist in the upper curves. Only the A2 point persists, on the other hand, in the lower curves, which correspond with samples in which microscopic examination reveals the complete absence of pearlite.

If, on the other hand, the graphitic fragments be taken, submitted to a heating at 950°, and their cooling be subjected to galvanometric observation, starting from that temperature, the A1 point is seen to reappear, and the resulting curves coincide afresh with the upper curves of Fig. 8.

V. Independence of the A1 and A2 Points—Characteristic Individuality of the Latter Point.

These results fully confirm the conclusions to which the previous considerations had led, namely, that of the particular appearance of the curve under each factor; the A1 and A2 points are therefore quite independent of each other, and may assume, in relation with one another, various positions on the temperature scale. Thus the A1 point may become merged with the A2 point, or may change places with it.

On the other hand, the gradual effacement of the A1 point, and its complete disappearance in the highly siliconised alloys (silicon, 5 to 6 per cent.), corresponds with the progressive transformation of the pearlite and the final disintegrational precipitation of graphite.

Lastly, if the A2 point can persist when the other two points A1 and A3 have disappeared, it must be acknowledged that it certainly has a real and distinct individuality. This is a conclusion upon which the authors feel themselves entitled to lay emphasis, seeing the numerous controversies to which this question has within late years given rise.

VI. INFLUENCE OF SILICON ON THE SOLUBILITY OF CARBON IN IRON.

In order to complete the data given above, relative to the separation of graphite in the iron-silicon alloys, the authors conceived it useful to investigate the solubility of carbon in different ferro-alloys containing variable proportions of silicon.

Their experiments related to five metals, obtained by melting very pure pig iron with ferro-silicon in a crucible. The descriptions and chemical compositions of these samples are given in the following table:—

No.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.
4185–17	1·97	2·23	0·25	0·014	0·018
4185–18	1·88	3·16	0·25	0·015	0·016
4185–19	2·08	4·22	0·26	0·016	0·016
4185–20	2·12	5·84	0·25	0·019	0·016
4185–21	2·01	6·77	0·26	0·016	0·016

The resulting ingots were, first of all, annealed for three hours at 1000° C. followed by slow cooling (80° per hour) which led to the complete transformation of the carbon into graphite. Sections 15 millimetres in thickness were then taken to serve for the tests (which were carried out with the technical precautions previously described by one of the authors in an earlier paper[1]) on the solubility of graphite in iron, that is to say, prolonged heating at a given temperature followed by sudden cooling; the removal, by an emery wheel, of the portions superficially oxidised, and the taking of drillings from the centre of the sample which were analysed for total carbon and for graphitic carbon, the difference giving the amount of carbon dissolved.

The results obtained are summarised in the following table:—

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[1] G. Charpy, *Comptes Rendus*, 1907, vol. cxlv. p. 1277.

Conditions of Heating.

Sample.	600° for 2 h. 40 m.		700° for 2 h. 30 m.		800° for 1 h. 30 m.		900° for 1 hour.		1000° for 1 hour.			
	Total Carbon.	Graphite.	Total Carbon.	Graphite.	Total Carbon.	Graphite.	Total Carbon.	Graphite.	Total Carbon.	Graphite.		
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
4185–17	1·93	1·89	2·03	1·96	1·98	1·39	1·88	1·09	2·03	0·87	0·87	0·91
4185–18	1·89	1·90	1·93	1·87	1·93	1·92	1·85	1·18	1·82	0·96	1·00	0·79
4185–19	2·04	2·09	2·15	2·07	2·12	1·83	2·09	1·93	2·03	1·28	1·34	1·37
4185–20	2·15	2·05	2·13	1·90	2·09	2·03	2·14	2·20	2·12	1·74	1·60	1·78
4185–21	2·05	1·97	2·01	1·98	1·98	1·91	2·04	1·88	1·97	1·67	1·77	1·78

Taking into consideration the degree of accuracy of the experiments, it may be deduced from these figures that the values of the solubilities are as shown in the following table:—

Sample.	Silicon per Cent.	Temperatures.				
		600°	700°	800°	900°	1000°
4185–17	2·23	0	0	0·6	0·8	1·1
4185–18	3·16	0	0	0	0·7	0·9
4185–19	4·22	0	0	0	0·2	0·7
4185–20	5·84	0	0	0	0	0·3
4185–21	6·77	0	0	0	0	0·2

These results were checked, on the one hand by Eggertz colour tests, and on the other by hardness tests carried out on the quenched samples.

As is well known, the Eggertz method does not allow of the determination of the true percentages of combined carbon present in the quenched samples; it yields, nevertheless, a qualitative result which, in this actual instance, clearly corroborates the gravimetric determinations given above. The carbon percentages, calculated according to the Eggertz method, are practically proportional to the percentages of dissolved carbon as determined by the differences between the direct determinations of the total carbon and of the graphite.

The hardness results on the quenched samples likewise show a variation with the composition and temperature, closely in the neighbourhood of that corresponding with the dissolved carbon. This is brought out by the following table, in which have been inserted the hardness numbers ascertained by the Brinell test with a ball 10 millimetres in diameter and under a pressure of 3000 kilogrammes:—

Sample.	Silicon per Cent.	Hardness after Quenching at				
		600°	700°	800°	900°	1000°
4185-17	2·23	131	133	375	483	329
4185-18	3·16	145	155	186	491	424
4185-19	4·22	159	159	170	418	444
4185-20	5·84	268	269	267	291	307
4185-21	6·77	300	283	268	285	cracked

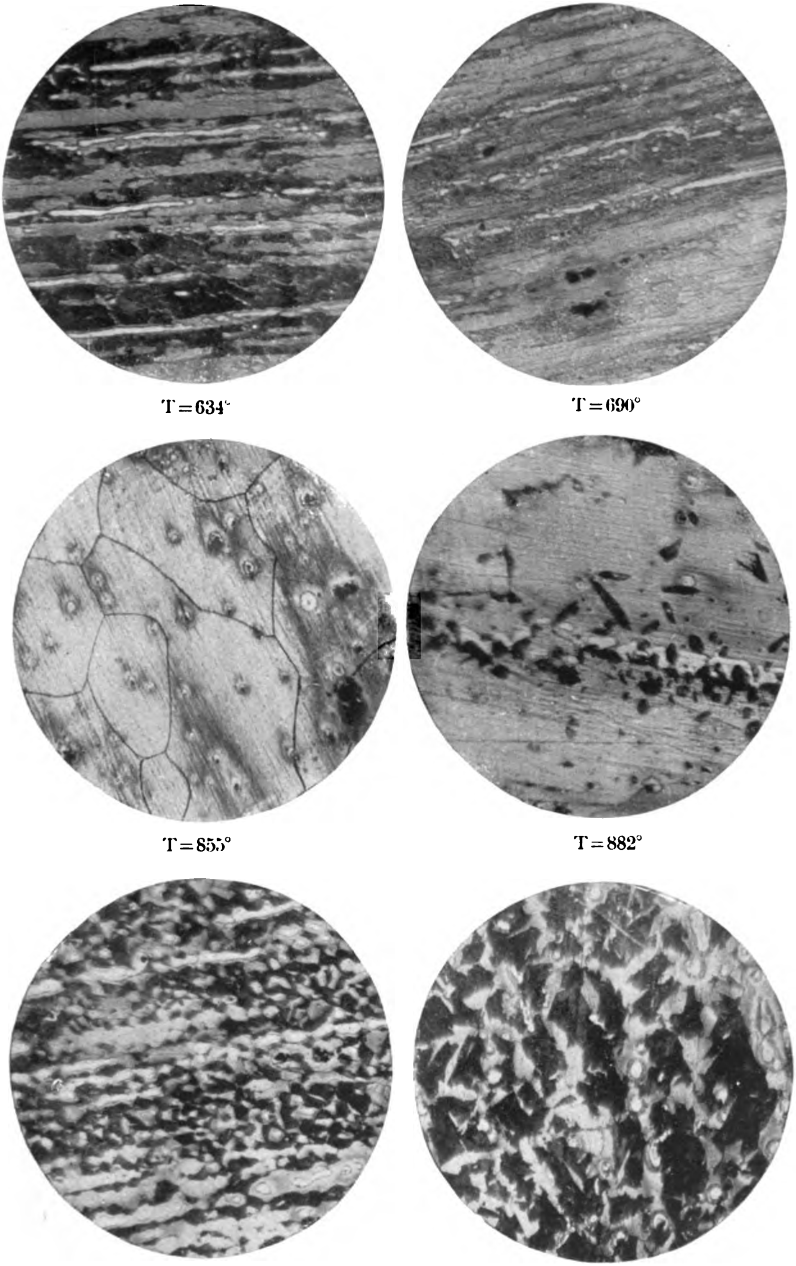
The indentations were made on a surface that had been ground on an emery wheel, and to a depth sufficient to eliminate the influence of surface oxidisation.

Silicon, therefore, gradually reduces the solubility of carbon in iron, which becomes practically nil at 900°, when the proportion of silicon reaches to 5 per cent., and at about 1000°, when the proportion of silicon exceeds 7 per cent.

VII. Critical Points in Irons containing Variable Percentages of Silicon.

The authors then set themselves to investigate the modifications imposed on the critical points by the introduction of a high proportion of carbon in the ferro-silicon alloys, and to endeavour to find a relationship between these modifications and the results previously obtained. With this object they completed the series of the five "4185" metals under investigation by adding to them two fresh alloys, the chemical composition of which was as follows:—

PLATE XLVII



T=634°

T=690°

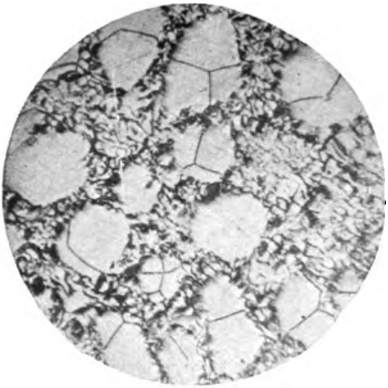
T=855°

T=882°

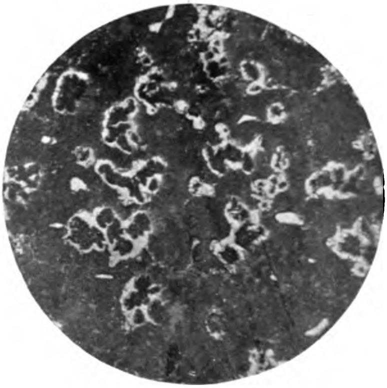
T=935°

T=1100°

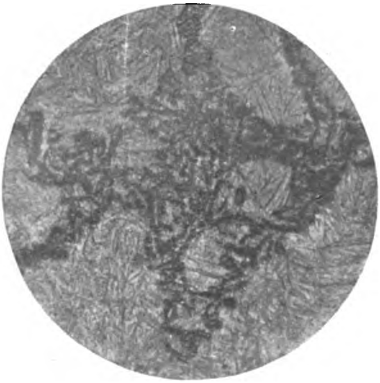
Photomicrographs made along different points of a bar of Sample 4081-III heated unequally along its length. Magnified 200 diameters, but reduced in reproduction. Etched with nitrified alcohol.



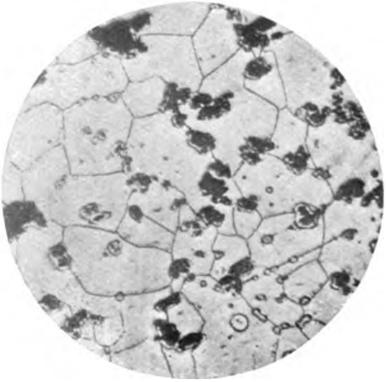
4185-20-II (after quenching at 875°)



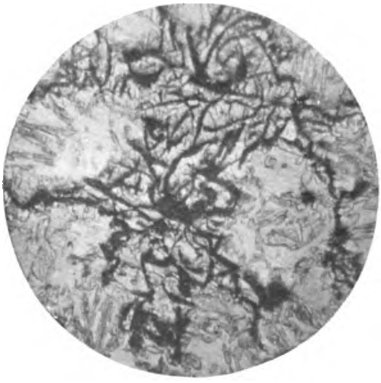
4185-21 III (after quenching at 1100°)



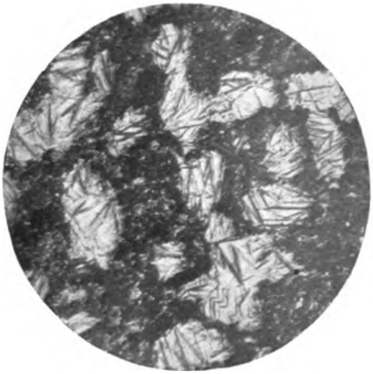
4185-19-III (after quenching at 1100°)



4185-20-II (after quenching at 875°)



4185-19-II (after quenching at 875°)



4185-20-III (after quenching at 1100°)

Photomicrographs of 3 Irons with varying Silicon percentages, quenched from 875° and 1100°. Magnified 200 diameters, and reduced in reproduction. Etched with nitrified alcohol.

	No. 4185-15.	No. 4185-16.
	Per Cent.	Per Cent.
Carbon	1·90	1·91
Silicon	0·14	0·13
Manganese	0·04	0·04
Phosphorus	0·011	0·017
Sulphur	0·054	0·057

On these seven carburised alloys the authors determined the positions of the critical point, the curves obtained by the double galvanometer being given in Fig. 9.

If these curves be compared with each other, one is, first of all, struck by the recurrence of the modifications undergone by the perturbation situated between 1100° and 1250°. This is the point corresponding with the completion of the solidification of the molten metal. It becomes more and more accentuated in proportion as the percentage of silicon becomes higher and rises simultaneously on the temperature scale, so that, although situated, during heating, at about 1130°, and during cooling at about 1190° in the sample No. 4185-15, it becomes found at about 1270° during heating, and about 1130° during cooling, in sample No. 4185-21. This amounts to a rise of about 20° for each percentage of silicon.

Let us now take into consideration the A2 point. Its very characteristic appearance, isolated on several previous occasions, allows of its being readily recognised. In the two first irons it is merged, during heating, with the A1 and A3 points, but it reappears on cooling below the two latter. It is again found, on heating, in the metal No. 4185-17 (silicon 2·2 per cent.) at about 760°, and may subsequently be followed regularly in the succeeding curves, and is found at 740° in the sample No. 4185-21 (silicon 6·7 per cent.). On cooling it occurs, in the latter alloy, at about 690°.

We again encounter, therefore, in this instance, the result previously met with in the steels: the lowering of the A2 point on the temperature scale, when the percentage of silicon rises, amounts to about 10° per 1 per cent. of silicon.

It remains to study the perturbation which the authors have regarded as the union of the A1, A2, and A3 points,

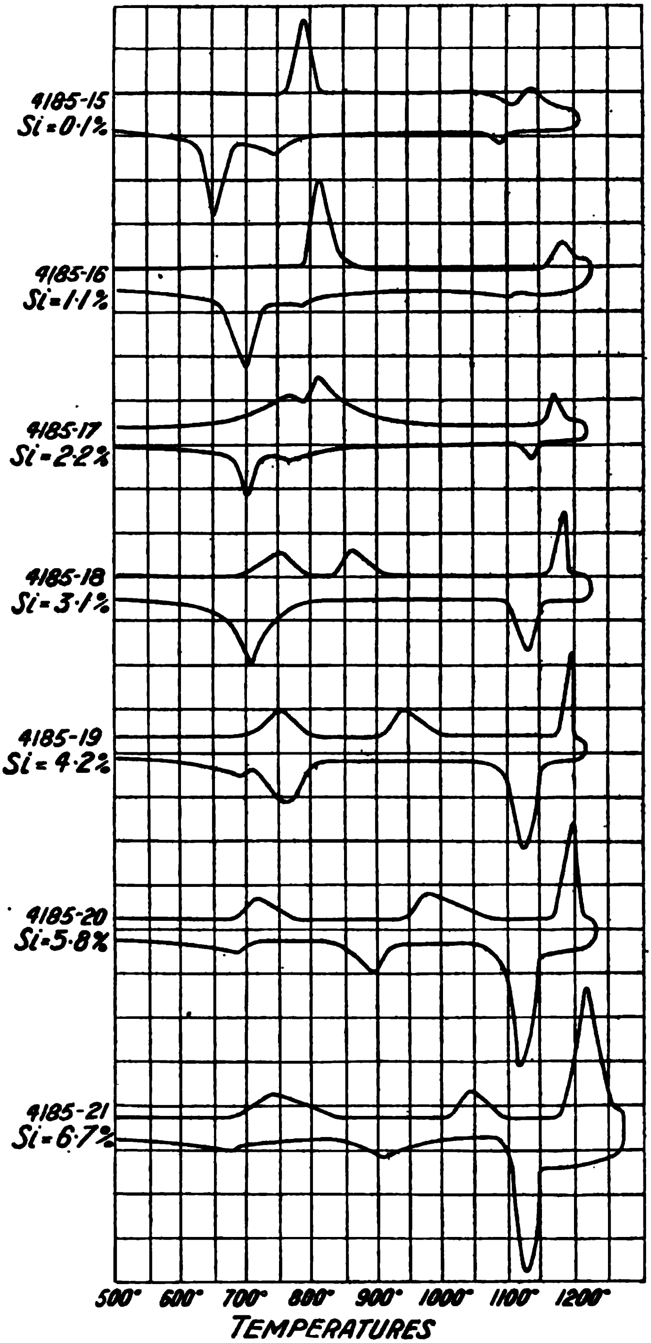


FIG. 9.—Critical Points of seven Crucible Irons with 2 per cent. of Carbon and varying percentages of Silicon.

during heating, in the alloy No. 4185–15. In proportion as the percentage of silicon rises this perturbation gradually changes its shape by flattening and losing the appearance of the A1 point, characterised by a sudden point. At the same time it rises rapidly on the temperature scale, so that, although situated at about 785° on the first curve (650° on cooling), it is found once again, at 1045°, on the latter (910° on cooling).

In accordance with what has already been said, we know that the A3 point disappears as soon as the proportion of silicon exceeds 1·3 per cent.; so that we cannot expect, from sample No. 4185–17 upwards, to find anything else intervening except either the A1 point or the thermal manifestation of some modification in the equilibrium of the iron-carbon-silicon system.

We know, on the other hand (see above), that, for a given temperature, when the percentage of silicon rises the solubility of the carbon diminishes. It may therefore be assumed that once the anomalous appearance of the A1 point is no longer met with—starting with metal No. 4185–18—the transformation appearing on the curves is nothing more than the formation of mixed crystals due to the passing into solution in the iron of the graphite previously present in the alloy.

To verify this point of view the authors proceeded in the following manner: An examination of the curves on heating shows that for the metals 4185–19, 4185–20, and 4185–21 the anomaly in question is situated between 875° and 1100°. If, therefore, the formation of mixed crystals takes any part, the latter should appear in the fragments of these alloys cooled suddenly from 1100°, whereas they should not occur in similar fragments treated at 875°. This experiment was carried out by quenching in water:

At 870°: the samples marked 4185–19–III, 4185–20–II, and 4185–21–II.
At 1100°: the samples marked 4185–19–III, 4185–20–III, and 4185–21–III.

The photomicrographs given (Plate XVLIII.) show that, as regards fragments of 4185–20–II and 4185–21–II (after quenching at 875°), the graphite stands out in black against a pale ground of ferrite, the joints of which are clearly distinguishable after etching with alcohol acidified with nitric acid. The formation of mixed crystals has not, therefore, commenced. In the fragments of 4185–20–III and 4185–21–III (after quenching at 1100°) the graphite, on the contrary, appears against a distinctly martensitic background. Besides this, the graphitic masses in the photomicrograph 4185–21–III (silicon 6·7 per cent.) are found encircled by unetched zones which seem to indicate the formation of a hard compound, apparently carburised ferro-silicon. In respect of these two irons the conclusion is therefore fairly clear.

In regard to metal 4185–19, the martensitic structure appears, but only very faintly, after the quenching at 875°; it is again met with in needles, much more clearly formed, after the quenching at 1100°. This result in no way vitiates the authors' hypothesis. As the curve shows, the temperature of 875° is too near to the temperature marking the commencement of the transformation to render it certain, given the cumulative influence of experimental errors and of varying rates of heating, that the heating, before quenching, had been carried out below the point under investigation. The comparison of the two photographs also shows clearly that, so far as fragment II is concerned, it is a case of a solution hardly begun, whereas, so far as fragment III is concerned, solution has been completed.

It may therefore be concluded that, both in silicon irons and in silicon steels, the A1 point disappears when, at the rate of temperature variation employed for the thermal test, the whole of the carbon finds itself normally decomposed. There then appears, however, a new point which the authors believe they have been able to define, by saying that it marks the formation of mixed crystals by the solution of the graphite in the iron. It should be noted, in conclusion, that these two occurrences may take place simultaneously, in one and the same sample.

SUMMARY.

It is possible briefly to sum up as follows the conclusions to which the present research have led, and to connect them with results already established:—

Influence of Silicon on the A1, A2, *and* A3 *Points.*—The authors are able to confirm, as different observers have pointed out, that the A3 point rapidly decreases when the percentage of silicon rises, at the same time rising very slightly on the temperature scale.

The temperature at which the A1 perturbation takes place rises with the silicon percentage, this point reaching and then passing the A2 point while becoming gradually fainter. After reaching a given percentage of the metalloid and for a given rate of variation of temperature, the A1 point completely disappears, and all the carbon of the metal is then found in the state of graphite. It is even possible to cause a predetermined disappearance of this point by treating the sample, before applying the thermal test, in such a manner as to produce the complete transformation of the carbon.

The A2 point fálls gradually in the temperature scale when the percentage of silicon rises, losing little by little its intensity the while, but still persisting in a very clear manner in metals containing up to 7 per cent. of the metalloid. At this juncture the A2 point is the only anomaly which appears on thermal investigation, in iron alloys containing low carbon, even when the rate of the variation in temperature be sufficiently accelerated. The individuality of the A2 point is the more clearly brought into light by the fact that it is possible, at will, to retain in or to eliminate from its vicinity the A1 point by bringing into play the precipitation of the graphite.

Although the A2 point is not manifested on dilatation, it is not impossible that it corresponds with an allotropic transformation. It is not necessary, from the authors' point of view, that for the definition of such a transformation it should manifest itself by its influence over the whole of the physical properties of the substance under consideration. It should suffice for it to influence any one of those properties.

Influence of Silicon on the Solubility of Carbon in Iron.—The present research is overshadowed by the following fact, which has already been pointed out by various observers, but which the authors believe themselves to have established in a more accurate manner than has hitherto been done: every increase in the proportion of silicon present in the metal diminishes the solubility of carbon in iron.

The presence of the metalloid reacts, naturally, on the one hand, on the temperature limits within which the precipitation of graphite takes place, and, on the other hand, on the rate of the transformation of the cementite. The authors have thus been able to show that with alloys containing very little carbon and about 3 per cent. of silicon, there exists a temperature zone within which, by making the rate of cooling intervene, the complete decomposition of the carbon may be brought about.

Finally, the influence of silicon on the rate of reaction is such that in certain irons the graphite precipitation gives rise to a thermal point. This anomaly, which may coexist with the A1 point, possesses special sharpness when the latter has disappeared. It is then found that it rises rapidly on the temperature scale, when the percentage of silicon rises.

Graphic Representation of the Phenomena.—The authors pointed out, at the beginning of this paper, that the researches on carburised ferro-silicon alloys appeared to them capable of affording information on those cases beyond its range where silicon was absent. It is well known that complete agreement has not been reached amongst metallurgists on the subject of the iron-carbon diagram. While most metallurgists favour the double diagram (graphite system and cementite system) described by Le Chatelier, Heyn, Charpy, Benedicks, &c., some observers appear to tend to revert to the single diagram, drawn up in the first instance by Roozeboom. Without entering into a detailed comparison, the authors would confine themselves to stating that all the facts they have observed and recorded in the present paper conform very naturally with the scheme of the double diagram, and thus appear to constitute a further argument in its support.

CORRESPONDENCE.

Dr. W. H. **Hatfield** (Sheffield) wrote that he had read the authors' paper with much interest. He invariably studied with care any work with which Mr. Charpy's name was associated, particularly since the advantage he had derived some years ago from a study of Messrs. Charpy and Grenet's admirable work upon the precipitation of carbon in iron-carbon alloys of varying silicon content. The present paper contained the results of a number of interesting experiments which required to be carefully studied, but there were several points in which he (Dr. Hatfield) was not in agreement with the authors. He had done much work in that field, and he thought the authors were unwise to deduce a fundamental change in their view of the iron-carbide system from the results of their experiments. For instance, they had no real evidence for stating (page 300, last paragraph) that the A1 point disappeared. It occurred upon their curves (see Fig. 9), but at a much higher temperature, and this fact was borne out by their interesting quenching experiments described upon page 295. He (Dr. Hatfield) deduced from their experiments that silicon merely modified (and that was confirmed by his own investigations) the thermal phenomena of the iron-carbide system. To say that "graphite" was soluble in iron was misleading. Would it not be better to consider that, at and above the raised critical temperature, the graphite formed carbide and entered into solution as such, and therefore on cooling came out as carbide, which then dissociated. Was there not some error in the temperatures given. (Compare Fig. I., curve 11–1011.) The perturbation indicated at 652° might have been expected to occur at 50° C. higher temperature. If that were so, possibly some of the other temperatures required correction.

Professor T. **Turner** (Birmingham) wrote that he had read with interest the paper dealing with a subject upon which he had already contributed several papers to the Institute. In the researches now under discussion, the authors had studied more particularly the low carbon alloys with less than the eutectoid proportion of carbon. In his (Professor Turner's) experiments, which included relatively high silicon, the proportion of carbon was about 3 per cent. Hence the points A3 and A2 were merged into the A1 or pearlite arrest at 700° or thereabouts. The two series of researches were, therefore, in some respects complementary to each other, but, in part, the same facts were observed. Thus, in the paper on "Silicon in Pure Cast Iron," by Hague and Turner,[1] it was shown (p. 88) that, as the silicon increased from 0 to 5 per cent., the lower arrest rose from 700° to 800°, while Messrs. Charpy and Cornu-Thenard stated that the point A1 rose with the silicon percentage, and after passing the A2 point became gradually fainter. Further, Hague and Turner found that the eutectic arrest-point at 1130° rose slightly but regularly over the whole series as the silicon increased. The rise of temperature at the high carbon end of the series was about 6° for each 1 per cent. of silicon. Messrs. Charpy and Cornu-Thenard also drew attention to the fact of that regular rise due to silicon, but at the low carbon end of the series the increase was found to amount to about 20° for each per cent. of silicon (p. 297). It was interesting also to notice the close similarity between the solubility of carbon in iron in the presence of silicon as now determined by Charpy and Cornu-Thenard, by annealing at a temperature of 1000°, and that already given by Hague and Turner in cast specimens of which the eutectic solidification point was about 1130°. It will be noted that where similar percentages of silicon were employed the agreement was remarkably good, while the figures for higher and lower percentages respectively, only given in one series, were just such as might be anticipated from the direction of the other values. Further points of similarity would be found on a close comparison of the two series of experiments. The authors were to be congratulated on their careful and accurate work upon that end of the series of alloys which, though chemically and mechanically examined by the writer in 1887,[1] had not been sufficiently studied from the point of view of thermal and volume changes.

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[1] *Journal of the Iron and Steel Institute*, 1910, No. II. p. 72.

Hague and Turner, 1910.		Charpy and Cornu-Thenard.	
Silicon per Cent.	Combined Carbon per Cent.	Silicon per Cent.	Solubility of Carbon per Cent.
0·97	2·33	...	...
1·50	1·29	...	...
2·18	1·04	2·23	1·1
3·06	0·84	3·16	0·9
4·03	0·79	4·22	0·7
4·83	0·64	...	...
...	...	5·84	0·3
...	...	6·77	0·2

Mr. **Charpy**, in his reply, thanked Dr. Hatfield for the reference he had made to his (Mr. Charpy's) previous work on the precipitation of graphite in iron-silicon alloys, and pointed out that the present paper fully confirmed the results previously obtained, while extending them to alloys containing low percentages of carbon. It was pleasing to note that the agreement between the results obtained on those alloys with those previously obtained by Mr. Hague and Professor Turner under different conditions allowed of the figures obtained being used with safety. Dr. Hatfield criticised the conclusion drawn as to the A1 point having disappeared, and considered that it would be better to say that it had been displaced. In the absence of a rigid definition of the A1 point it was obviously somewhat difficult to affirm that it had disappeared as long as the cooling curve still revealed certain perturbations, but the expression which the authors had adopted was that it appeared to them to represent most faithfully the observed facts and the gradual modifications introduced into the curves by variations in the percentages of silicon. With regard to the numerical value of the temperatures of the critical points, they were given just as they had been obtained under the experimental conditions employed; as these conditions influenced the position of the critical points, the temperatures indicated had chiefly a relative value, as was the case in all investigations of that type. The use of the words "solubility of the graphite" was criticised by Dr. Hatfield. As regards everything relating to dissolution phenomena, the authors believed that the statement adopted by Bakhuis Roozeboom as a conclusion to his celebrated investigations on the solid and liquid compounds of water with salts should be adhered to. In that statement he said, "I believe that it is not possible at the present time to decide whether the whole of the molecules of a salt are permeated in the same way by the molecules of water, or whether there exist different complexes the number and composition of which vary with the concentration and the temperature." He could not go beyond the following statement, "The constitution of a dissolved salt differs from that of an anhydrous salt as much as from that of all the hydrates which are capable of being formed at a given temperature." In the present instance it therefore appeared to the authors useless to ascertain whether the carbon dissolved in the iron was in a state of graphite or iron carbide, or in any other state, as that would be "going further than the statement" of Roozeboom and would add nothing to the observed facts.

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[1] *Journal of the Chemical Society*, vol. li. p. 129 *et seq.*

THE THERMO-ELECTRIC PROPERTIES OF SPECIAL STEELS.

By EUGENE L. DUPUY (Versailles) and ALBERT M. PORTEVIN (Paris).

I. Historical.

Researches on thermo-electricity can be classed in two categories: (1) Those which have as their object the examination of the variation in thermo-electric properties with variations in temperature, and, in particular, the determination of the critical points, which are manifested by abnormalities in the law of variation, and (2) those in which the variation in these properties are determined at a given temperature, but in terms of the variation in the chemical composition and in the heat treatment of the material under investigation.

In the first series of experiments which were the object of this paper the authors have only taken into consideration the study of the thermo-electric force within two given temperature ranges—80° C. to 0° C. and 0° C. to 100° C. The determination of these two constants, for each alloy, does not allow of the curve representing the variation in thermo-electrical force with temperature variations being plotted, this curve belonging to the second category at least. In the experiments still in course of being carried out, they propose to plot those curves by direct measurement for each alloy.

While the investigation of the thermo-electric properties of the ordinary carbon steels, that is to say of the iron-carbon alloys, have already been the object of relatively numerous researches, amongst which may be mentioned those of Frantz (1851), Joule (1859), Tait (1872), Barus (1879), Strouhal and Barus (1880 and 1883), Dewar and Fleming (1895), Jaegar and Disselhorst (1900), and Belloc (1900), the thermo-electric properties of the special steels, that is to say of iron-carbon alloys containing, in addition, one or more elements, have, on the other hand, only been investigated by a very small number of experimenters. The authors can only recall the work of Steinmann,[1] who failed to find, in respect of nickel steels, any simple relationship between thermo-electric force and composition; Belloc,[2] who, in determining the thermo-electric force as compared with that of platinum, on these same samples, and the displacement of the neutral point with variation in composition, obtained analogous results; and, finally, Boudouard,[3] who likewise employed a thermo-electrical method for the determination of the transformation points of nickel steels.

II. MATERIAL AND TREATMENTS.

The determinations bore on a very nearly complete series of special steels comprising 27 nickel steels, 17 chromium steels, 4 manganese steels, 7 aluminium steels, 7 silicon steels, 10 tungsten steels, 8 molybdenum steels, and, in addition, 7 very pure ordinary carbon steels, and a sample of electrolytic iron which had served for the determination of the starting point for each series, or, in all, 88 different samples. The complete chemical analyses of all these steels are given in Table I.

Heat Treatment.—The steels were tested both in the annealed and in the hardened states. The conditions of treatment are shown in Table II.

TABLE I.—*Composition of the Steels.*

Carbon Steels.

No.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Arsenic per Cent.
Electrolytic iron .	...	0	0	0·025	...	0·011
H1	0·07	0·00	0·03	0·005	0·013	...
H2	0·24	0·03	0·03	traces	0·015	...
H3	0·44	0·05	0·08	,,	0·016	...
H4	0·79	0·00	0·09	0·006	0·009	...
H5	1·12	0·02	0·06	traces	0·022	...
H6	1·58	0·04	0·09	,,	0·016	...

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[1] *Comptes Rendus*, 1900, vol. cxxx. p. 1300.

[2] *Ibid.*, 1902, vol. cxxxiv. p. 105.

[3] *Revue de Métallurgie*, 1904, p. 80.

TABLE I.—*Composition of the Steels (continued).*

Nickel Steels.

No.	Carbon per Cent.	Nickel per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.
1N2	0·07	2·23	0·07	0·02	0·006
1N5	0·12	5·23	0·05	0·01	0·004
1N7	0·12	7·13	0·05	0·12	0·005
1N10	0·13	10·10	0·10	traces	0·005
1N12	0·12	12·07	0·09	,,	0·002
1N15	0·11	15·17	0·02	,,	0·004
1N20	0·18	20·40	0·02	,,	0·004
1N25	0·16	25·85	0·04	,,	0·007
1N30	0·12	30·00	0·03	,,	traces
4N2	0·21	1·97	0·03	0·02	traces
4N5	0·20	4·90	0·04	0·02	0·03
4N7	0·23	7·59	0·08	0·05	traces
4N10	0·21	9·79	0·01	0·02	,,
4N12	0·22	12·29	0·01	0·02	0·002
4N15	0·22	15·04	0·05	traces	0·002
4N20	0·22	20·01	traces	0·02	0·003
4N25	0·23	25·06	0·08	0·02	0·003
4N30	0·19	27·87	0·03	0·02	0·002
9N2	0·80	2·20	0·10	0·10	0·005
9N5	0·78	4·90	0·08	0·09	0·004
9N7	0·81	7·09	0·10	0·12	0·003
9N10	1·05	9·79	traces	0·10	0·004
9N12	0·76	12·27	0·09	0·09	0·004
9N15	0·80	15·04	0·09	0·06	0·007
9N20	0·80	20·01	0·09	0·02	0·003
9N25	0·79	25·06	traces	0·07	0·002
9N30	0·81	29·96	0·14	0·03	0·004

Chromium Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.	Chromium per Cent.
1C1	0·06	0·70	0·016	traces	traces	1·20
1C2	0·08	0·12	0·015	,,	0·08	1·89
1C3	0·28	0·05	0·010	,,	0·15	2·66
1C7	0·07	0·12	0·010	0·014	traces	7·84
1C10	0·42	0·35	0·010	traces	,,	9·80
1C12	0·14	0·21	0·016	0·015	,,	13·60
1C25	0·24	0·26	0·022	0·013	0·10	25·31
1C30	0·46	0·37	0·024	0·006	traces	31·75
8C1	0·97	0·22	0·013	0·016	0·24	0·92
8C2	0·89	0·28	0·020	0·033	0·10	2·14
8C5	0·79	0·42	0·016	0·023	traces	4·57
8C7	0·84	0·41	0·018	0·031	0·05	7·27
8C10	0·52	0·62	0·024	0·005	0·13	9·85
8C12	0·96	0·41	0·013	0·047	0·05	11·52
8C20	0·90	0·74	0·010	0·007	0·05	18·65
8C25	0·82	0·58	0·016	0·008	0·05	26·54
8C30	0·92	0·47	0·021	0·012	0·05	32·46

TABLE I.—*Composition of the Steels* (*continued*).

Molybdenum Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.	Molybdenum per Cent.
1Mo0·5	0·19	0·12	0·018	0·009	0·07	0·45
1Mo1	0·16	0·11	0·018	0·032	0·10	1·00
1Mo2	0·14	0·12	0·021	0·009	0·17	2·20
1Mo5	0·29	0·12	0·026	0·039	0·50	4·50
8Mo0·5	0·77	0·21	0·021	0·032	0·26	0·50
8Mo1	0·81	0·02	0·040	0·018	0·40	1·21
8Mo2	0·81	0·17	0·016	0·034	0·30	1·98
8Mo5	...	...	...	...	...	...

Manganese Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.
8M0·5	0·87	1·35	0·020	0·024	0·40
8M1	0·84	0·57	0·024	0·015	1·03
8M3	0·93	1·44	0·015	0·010	3·08
8M12	0·96	0·87	0·011	0·013	12·09

Aluminium Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.	Aluminium per Cent.
1A2	0·17	traces	0·008	0·022	traces	2·04
1A3	0·13	0·10	0·016	0·013	,,	3·04
1A7	0·08	0·18	0·020	0·017	0·06	7·18
8A5	0·81	0·22	0·024	0·024	0·12	4·65
8A7	0·66	0·26	0·025	0·050	0·14	7·00
8A10	0·67	0·11	0·034	0·024	0·09	9·15
8A15	0·86	0·23	0·032	0·018	0·40	14·90

Silicon Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.
1S0·5	0·21	0·41	0·117	0·061	0·72
1S1	0·21	0·93	0·024	0·020	traces
1S2	0·18	1·60	0·032	0·012	0·27
1S3	0·28	5·12	0·034	0·009	0·38
8S1	0·84	1·16	0·021	0·017	0·57
8S2	0·83	1·15	0·021	0·017	0·41
8S3	0·94	5·54	0·062	0·017	1·44

TABLE. I.—*Composition of the Steels (continued).*

Tungsten Steels.

No.	Carbon per Cent.	Silicon per Cent.	Phosphorus per Cent.	Sulphur per Cent.	Manganese per Cent.	Tungsten per Cent.
1T0·5	0·18	0·03	0·013	traces	traces	0·41
1T1	0·11	0·06	0·016	0·005	,,	0·93
1T2	0·11	0·03	0·010	0·008	,,!	1·75
1T5	0·13	0·03	0 015	traces	,,	4·96
1T15	0·20	0·06	0·013	0·008	,,	14·37
1T20	0·22	0·14	0·011	0·013	,,	20·71
8T0·5	0·86	0·04	0·012	0·033	0·027	0·40
8T2	0·66	0·12	0·015	0·023	0·054	0·95
8T10	0·81	0·09	0·015	0·014	traces	9·99
8T15	0·71	0·12	0·015	0·023	,,	14·74

Annealing was carried out in magnesia for the steels with low percentages of carbon, and in iron drillings for those more highly carburised, in order to diminish surface decarburisation. The time the steels remained in the furnace was about three hours, of which one hour was allowed for the equalisation of the temperature. The periods of cooling, which are shown in Table II., depended, obviously, on the sizes of the annealing-boxes.

TABLE II.—*Heat Treatment of the Thermo-electric Test-pieces.*

Steels.	Annealed.[1]			Hardened.		
	Tempera-ture of Furnace.	Period of Heating.	Period of Cooling.[2]	Tempera-ture of Furnace.	Period of Heating.[3]	Tempera-ture of Water.
	Deg. C.	Hours.	Hours.	Deg. C.	Minutes.	Deg. C.
Nickel . .	900	3	7	950	13	18
Chromium . .	1000	3	7	1000	12	11
Carbon . .	900	3	8½	950	11	15
Tungsten . .	900	3	8½	1000	11	14
Aluminium .	900	3	8¾	1000	11	14
Molybdenum .	900	3	8¾	1000	11	14
Silicon . .	900	3	5	1000	11	14
Manganese .	900	3	5	1000	11	14

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[1] In magnesia for steels with low percentages of carbon. In pig-iron turnings for steels with about 0·8 per cent. of carbon in order to diminish decarburisation.

[2] Varying with the size of the annealing-boxes.

[3] Effected so that the test-pieces should remain at the furnace temperatures for two minutes.

Hardening was effected by immersing the bars, in a nearly horizontal position, in water, in order to secure the most equable conditions along the entire length of the bars during quenching.

III. METHODS AND APPLIANCES FOR MEASUREMENT.

The thermo-electric force has been measured between the temperatures – 78° and 0°, and 0° and 100°, these temperatures having been selected on account of the ease with which they can be obtained and maintained during the progress of the experiments. The 0° and 100° C. points are, of course, obtained with melting ice and boiling water respectively, – 78° C. being the boiling temperature of a solution of carbonic acid snow in acetone at atmospheric pressure.

The samples, taken in the form of rolled bars 20 millimetres in diameter, were cut to lengths of 35 or 45 centimetres, and the ends were dressed down, either on a lathe or by means of an emery-wheel, to a diameter of 5 millimetres, over a length of 80 millimetres. The small diameter of the ends was adopted to insure the equalisation of the temperature between the steel and the bath at constant temperature. On the other hand, the great length entirely obviated the transmission of heat from one end to the other, owing to the low thermal conductivity of the bar, and the error that would consequently arise in the temperature. These bars are represented in Fig. 1.

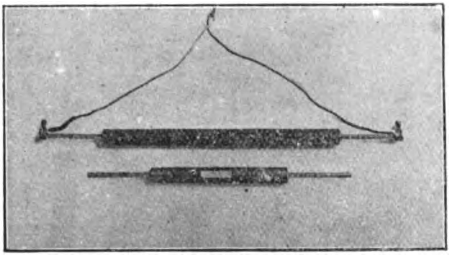

FIG. 1.—Test-bars and arrangement of Connections. Scale $\frac{1}{10}$.

After each heat treatment (quenching or annealing) the ends of the bars were carefully scrubbed either with a wire brush or with emery in order to obtain an absolutely clean and bright surface.

The thermo-electric force was measured by comparison with the copper of the connecting wires, and ultimately standardised against a sample of pure lead, which helped, throughout the entire series of experiments, to check the constancy of the readings of the measuring appliances.

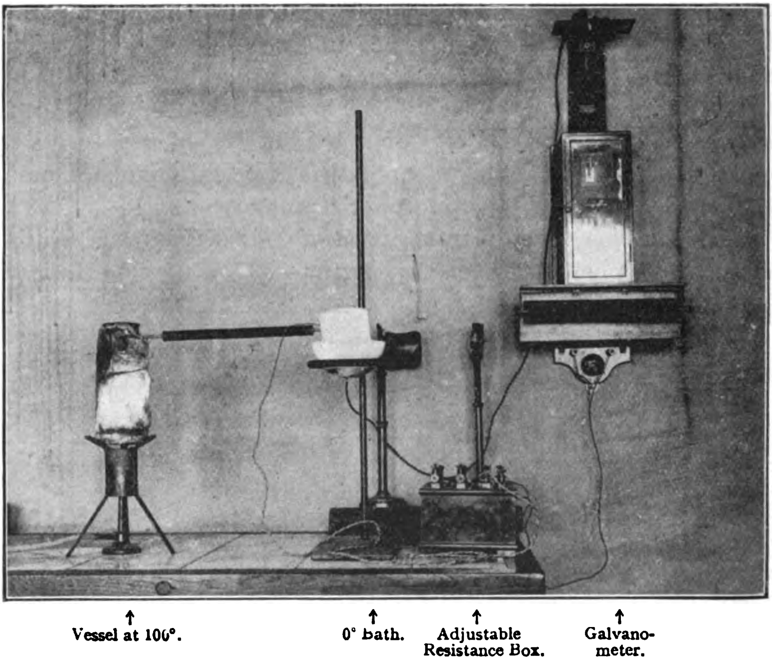

FIG. 2.—Arrangement of Measuring Apparatus.

Contact between the copper wire and the sample was secured by a little brass tightening rod soldered to the copper conductor and furnished with a steel screw which allowed of an effective tightening up. Preliminary tests showed that this device would allow of absolutely constant results being obtained on any one sample, and completely avoided imperfect contact. In Fig. 1 the upper sample is shown to be furnished with its two contacts for measuring.

The two ends of the sample, thus prepared and forming the hot and the cold junctures of a thermo-electric battery, were placed respectively either in a tube containing boiling water (point 100° C.) and a beaker containing melting ice (point 0° C.), or in a beaker filled with a mixture of carbonic acid snow and acetone (point – 78·6° C.) and a beaker containing ice. The thermo-electric energy thus developed was measured by the deviation of a Desprez-d'Arsonval galvanometer used as a microvolt meter and placed against a solid masonry pier out of the way of vibrations. The high resistance of this movable frame (199·6 ohms) allows of that of the outer circuit being neglected, and renders the deviations practically proportionate to the electromotive forces developed. A box of standardised resistances placed in series in the circuit serves to diminish the sensitiveness of the galvanometer, with certain samples which would yield wide deviations.

The standardisation of the galvanometer as a voltmeter was effected by means of a standard Weston cell, by the method of double position.

IV. Results.

The readings of the deviation of the galvanometer gave the total electro-thermal force for the intervals under consideration (– 78° to 0° C. and 0° to 100° C.), as compared with copper. Let D_1 and D_2 be these deviations, and Δ_1 and Δ_2 those given by the standard sample of lead under similar conditions. The total deviations as compared with copper are:

$$d_1 = D_1 - \Delta_1$$
$$d_2 = D_2 - \Delta_2$$

and the average force P per degree for a temperature interval t

$$P = \frac{d}{t}$$

whence, if K be the galvanometer constant, we have, in millivolts:

$$P = K \, . \, \frac{d}{E}$$

which with the galvanometer, and the temperature intervals adopted, gives:

$$P_1 = -0{\cdot}116\ D_1$$
$$P_2 = 0{\cdot}001\ D_2$$

The authors will give the numerical results obtained with each series of steels in the form of tables. By means of these tables curves have been plotted representing the average variation in the thermo-electric force between − 78·6° to 0° C. and 0° to 100° C. for the annealed and the hardened steels containing similar percentages of carbon, in terms of the percentage of the special element added.

Carbon Steels (Table III. and Fig. 3).

The thermo-electric force diminishes with the carbon percentage both in annealed and in hardened steels. Up to about 1 per cent. of carbon this diminution is sufficiently uniform to be represented, in terms of the carbon percentage, by a linear formula.

TABLE III.—*Carbon Steels.*

No.	Annealed.		Hardened.		Carbon per Cent.
	−80°	+100°	−80°	+100°	
Electrolytic iron .	+12·20	+8·70	...	...	...
H1 . .	11·71	8·55	12·35	8·73	0·07
H2 . .	10·90	7·65	9·81	6·93	0·24
H3 . .	9·50	6·20	5·10	3·46	0·44
H4 . .	7·90	5·40	0·92	−1·32	0·79
H5 . .	5·90	4·10	−5·15	−5·70	1·12
H6 . .	6·61	4·15	−6·40?	−15·80	1·58

Thus, for these percentages the authors have derived, from the values given by the six samples H1 to H6, the following ratios:

(1) *Annealed Steels.*

Millivolts per Degree.

Between − 78° and 0° $P_1 = -5{\cdot}6\ C + 12{\cdot}2$

" 0° " 100° $P_2 = -4{\cdot}6\ C + 8{\cdot}7$

(2) *Hardened Steels.*

		Millivolts per Degree.
Between	-78° and 0°	$P_1 = -16{\cdot}7\,C + 13{\cdot}5$
,,	0° ,, 100°	$P_2 = -13{\cdot}9\,C + 9{\cdot}9$

It will be seen that the decrease in thermo-electric force with that of carbon percentage is much more rapid in the hardened steels than it is in the annealed steels, which is doubtless due to the passage of the carbon into solid solution consequent on quenching.

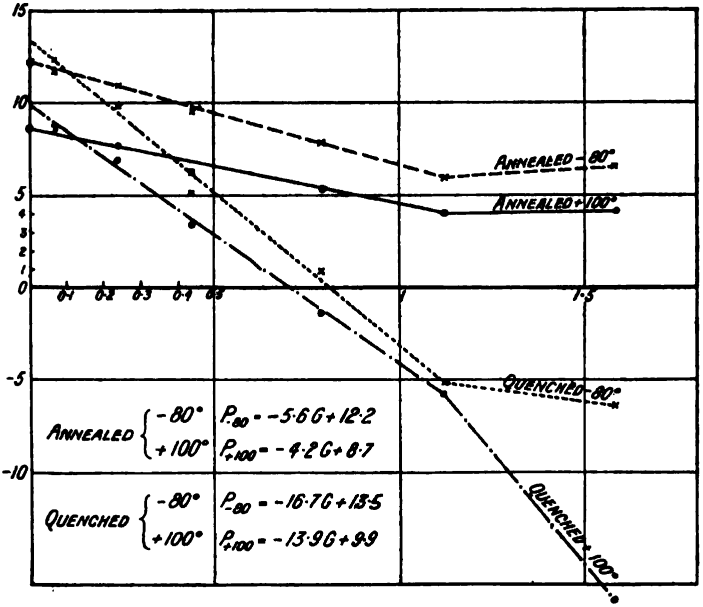

FIG. 3.—Thermo-electric Properties of Iron-carbon Alloys.

If in the foregoing formulas relative to annealed steels C is taken as equal to 0 (pure iron) we obtain:

$$P_1 = +12{\cdot}2$$
$$P_2 = +\ 8{\cdot}7$$

values which have since been found to be accurate by direct determinations made on electrolytic iron.

Nickel Steels (Table IV. and Figs. 4 to 9).

All the curves representative of the thermo-electric force in terms of the percentage of nickel show a very rapid decrease followed by a very clearly marked minimum. This minimum corresponds with a nickel percentage in the vicinity of that which corresponds with the limit between austenitic steels and martensitic steels. The ascending branch has an affinity, therefore, with the solid solution γ-iron-carbon-nickel. A similarity between these results, and those obtained by one of the present authors[1] when determining the curve of the electrical resistance of these steels, may be detected.

TABLE IV.—*Nickel Steels.*

No.	Untreated.		Annealed.		Hardened.	
	-80°	+100°	-80°	+100°	-80°	+100°
1N2 . . .	+8·8	+6·5	+8·9	+6·3	+10·7	+6·2
1N5 . . .	-0·6	-3·2	-0·6	-3·5	+ 0·2	-3·4
1N7 . . .	-4·8	-7·6	-4·8	-7·8	- 4·9	-7·6
1N10 . . .	11·0	13·5	10·6	14·6	10·9	9·7
1N12 . . .	18·1	17·4	14·3	16·9	14·5	17·0
1N15 . . .	19·9	24·3	19·0	23·5	18·4	23·9
1N20 . . .	27·3	30·0	28·4	30·4	32·6	31·3
1N25 . . .	30·5	27·8	31·4	11·5	32·6	31·3
1N30 . . .	15·2	1·5	14·8	6·9	14·7	1·0
4N2 . . .	+8·1	+6·3	+8·5	+7·0	+7·9	+5·5
4N5 . . .	0·0	-2·3	1·7	-2·4	0·7	2·0
4N7 . . .	-4·3	6·8	4·1	7·3	-3·2	-6·0
4N10 . . .	9·4	12·9	9·7	12·6	9·7	11·6
4N12 . . .	13·4	16·4	13·0	15·3	11·7	15·7
4N15 . . .	17·4	19·6	16·3	27·3	16·0	19·1
4N20 . . .	22·0	21·5	21·4	30·6	22·0	23·7
4N25 . . .	14·6	3·8	17·4	7·1	19·6	12·7
4N30 . . .	4·1	1·9	7·9	2·3	9·2	0·9
9N2 . . .	+5·7	+4·6	+ 6·4	+4·7	+5·8	+4·6
9N5 . . .	-1·0	-2·6	+12·3	-3·0	-1·0	-2·6
9N7 . . .	3·9	5·9	- 5·0	6·9	4·1	5·9
9N10 . . .	8·0	8·7	7·2	8·5	7·1	8·5
9N12 . . .	10·1	10·4	7·8	9·4	8·7	9·8
9N15 . . .	9·2	4·9	11·9	11·1	10·1	10·1
9N20 . . .	6·8	3·5	12·3	6·6	5·0	5·0
9N25 . . .	2·9	2·6	12·2	6·1	4·6	4·9
9N30 . . .	2·9	1·9	5·6	1·8	3·3	2·0

It is also of interest to note the differences in the thermo-electric force between −78° and 0° on the one hand, and between 0° and 100° on the other, for some of these steels, such as 1N30, 4N25, 9N20, and 9N25 (in these two last examples the steels were annealed), which show the influence of the transformation point.

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[1] A. Portevin, *Carnegie Scholarship Memoirs*, 1909, vol. i. pp. 302 *et seq.*

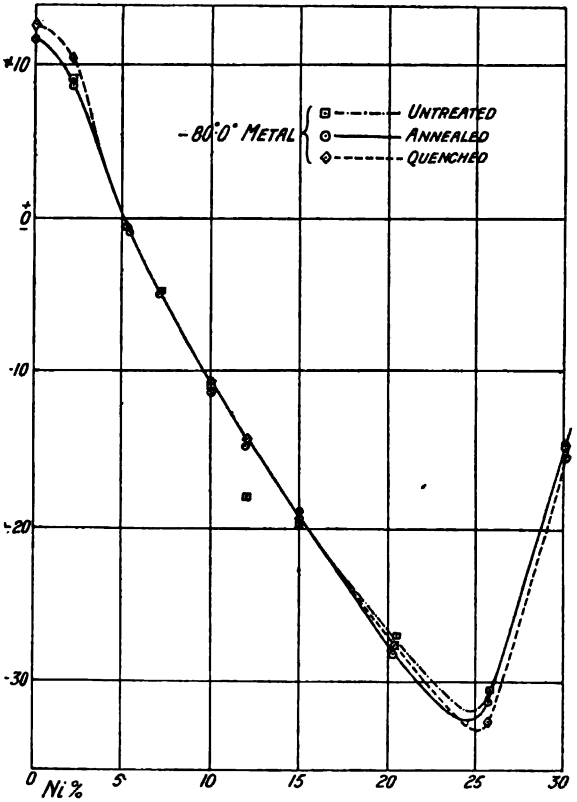

Fig. 4.—Nickel Steels with 0·1 per cent. Carbon.

The thermo-electric force shows itself in these steels, as one of the properties most sensitive to the action of nickel. This sensitiveness is specially marked in the steels with low percentages of carbon.

Hardening has a hardly appreciable influence on the thermo-electric force, in the series of steels containing 0·8 per cent. of carbon.

Chromium Steels (Table V. and Figs. 10–13).

If the curves representative of the annealed steels be considered there will be noticed, in connection with three of these steels, that they present the same appearance, that is to say, the chromium, after having made the electromotive force slightly increase, makes it fall to lower values, followed by a slight increase again, in the carburised steels. The influence of chromium is much less marked than that of nickel. Generally speaking, hardening diminishes the thermo-electric force, but the earlier additions of chromium gave,

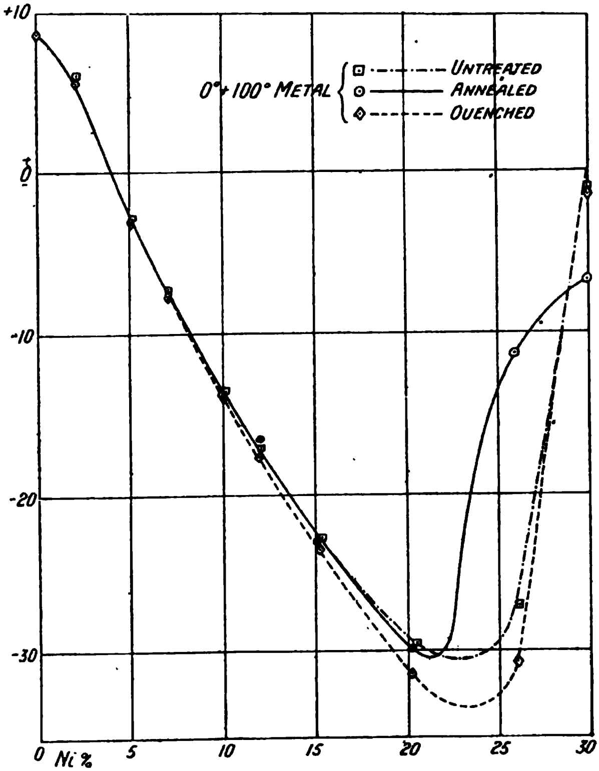

FIG. 5.—Nickel Steels with 0·1 per cent. Carbon.

in the hardened steels, irregular variations which have not been plotted as curves. A few of the determinations have also been omitted because of the cracks that invariably occurred in the test-pieces of some of the steels no matter what precautions were observed during quenching.

TABLE V.—*Chromium Steels.*

No.	Untreated.		Annealed.		Hardened.	
	−80°	+100°	−80°	+100°	−80°	+100°
1C1	+17·1	+16·6	+17·53	+16·93	+6·70	+16·4
1C2	15·2	16·6	15·43	16·65	14·50	15·20
1C3	14·70	17·10	16·94	18·11	14·60	21·50
1C7	8·50	12·70	9·75	14·92	9·80	13·50
1C10	6·84	5.82	12·18	14·74	Cracked	
1C12	6·15	8·73	6·50	10·56	5·10	7·65
1C25	4·17	6·28	6·26	9·01	6·28	5·09
1C30	5·92	9·55	4·29	6·55	4·99	7·86
8C1	+9·51	+8·83	+9·74	+8·92	+3·90	+3·64
8C2	9·51	9·00	10·21	9·64	3·52	4·20
8C5	12·30	12·90	12·18	12·56	7·10	5·91
8C7	10·20	11·90	11·60	13·45	Cracked	
8C10	2·78	3·63	11·48	14·48	4·98	3·58
8C12	9·41	11·90	10·40	13·60	6·90	9·70
8C20	0·81	−1·55	4·99	7·95	3·25	4·64
8C25	2·90	+5·37	3·30	5·91	2·00	4·64
8C35	4·87	6·28	6·84	6·30	4·32	5·55

TABLE VI.—*Tungsten Steels.*

No.	Annealed.		Hardened.	
	−80°	+100°	−80°	+100°
1T0·5	+9·00	+6·30	+8·40	+5·70
1T1	8·40	5·98	7·70	5·65
1T2	7·60	5·24	6·70	4·75
1T5	7·80	6·25	7·20	5·20
1T15	7·60	6·40	7·80	7·40
1T20	7·85	6·30	7·90	7·25
8T0·5	+1·80	−0·08	−1·60	−4·15
8T2	2·50	+0·50	+1·10	1·70
8T10	4·90	3·00	2·80	+1·30
8T15	2·70	0·60	0·00	−1·40

Tungsten Steels (Table VI. and Figs. 14–15).

In the two series of steels with 0·1 and 0·8 per cent. of carbon respectively, the effect of tungsten begins to make itself felt by a very rapid lowering of the thermo-electric force, followed by a rise. The latter, which is only faintly marked in the steels with 0·1 per cent. of carbon is, on the contrary, accentuated in those with 0·8 per cent. of carbon, and is followed by a maximum. The characteristic curve then affects the very well-defined shape of a horizontal S, to which reference will be made when summarising the conclusions. Quenching does not in any way alter the general form of the curves but, taking them in the aggregate, it lowers the thermo-electric force.

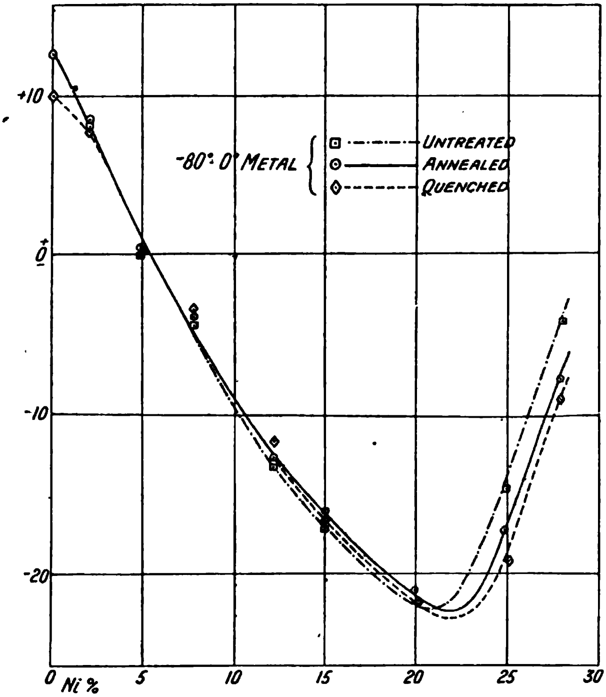

FIG. 6.—Nickel Steels with 0·25 per cent. Carbon.

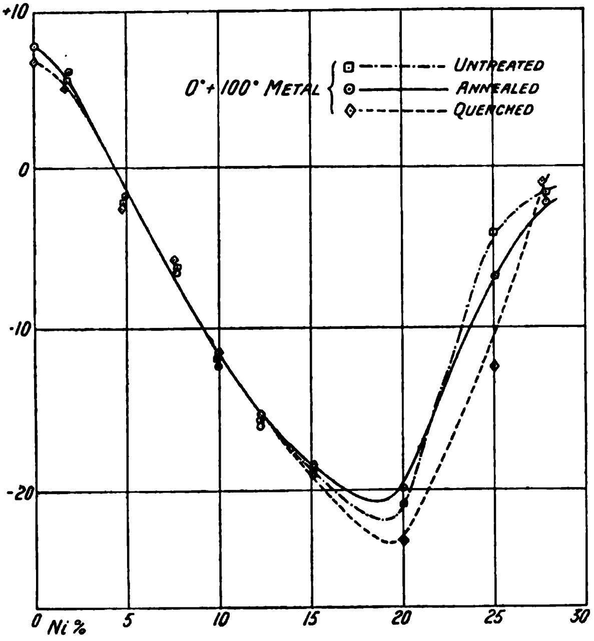

FIG. 7.—Nickel Steels with 0·25 per cent. Carbon.

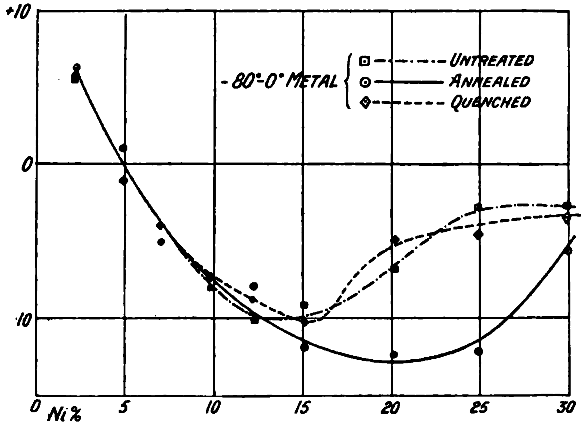

FIG. 8.—Nickel Steels with 0·8 per cent. Carbon.

Molybdenum Steels (Table VII. and Figs. 16, 17).

In the series of steels with low carbon percentages the influence of the molybdenum on the thermo-electric force is but little appreciable so long, that is, as the percentage of molybdenum does not exceed 5 per cent.

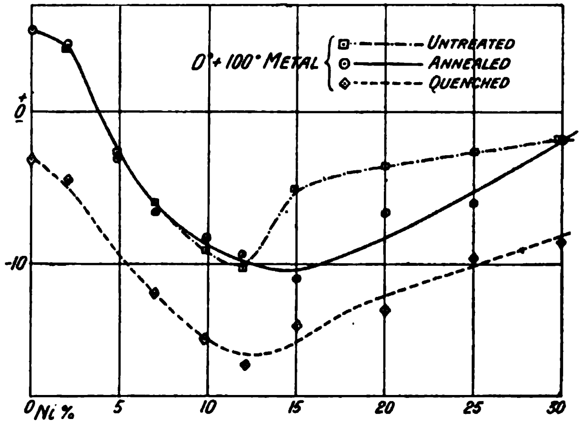

FIG. 9.—Nickel Steels with 0·8 per cent. Carbon.

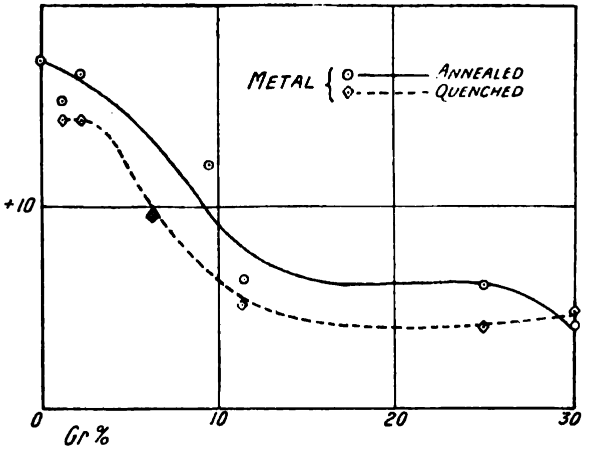

FIG. 10.—Chromium Steel with 0·1 per cent. Carbon, 80° – 0°.

With regard to the carburised steels, and in spite of the relatively small number of determinations, the same form of curve is met with as for the chromium steels, so far as the variation in thermo-electric force with variation in percentage of molybdenum is concerned.

The thermo-electric force is lowered on quenching, particularly as regards the steels containing 0·8 per cent. of carbon.

TABLE VII.—*Molybdenum Steels.*

No.	Annealed.		Hardened.	
	-80°	+100°	-80°	+100°
1Mo0·5	+10·00	+8·35	Cracked	
1Mo1	10·80	7·70	+10·00	+8·00
1Mo2	10·70	7·80	10·10	7·92
1Mo5	8·60	6·30	-12·00?	3·98
8Mo0·5	+4·50	+3·00	-4·40	-6·50
8Mo1	4·70	3·20	Cracked	
8Mo2	5·20	4·30	+1·10	+0·10
8Mo5	0·30	-2·10	Cracked	

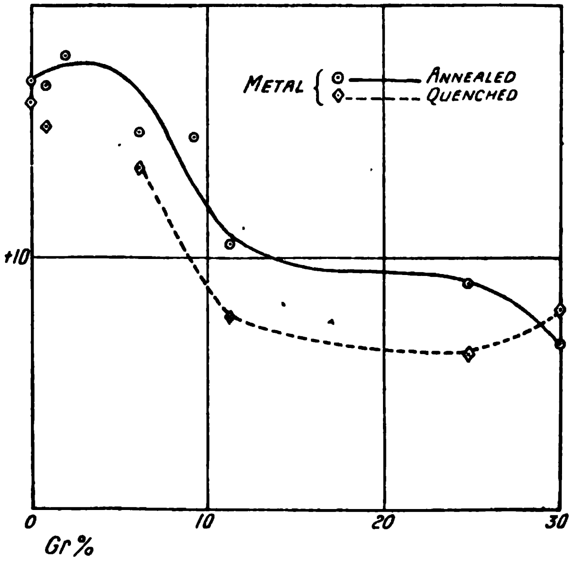

FIG. 11.—Chromium Steels with 0·1 per cent. Carbon, 0°+100°.

Silicon Steels (Table VIII. and Figs. 18, 19).

The influence of silicon on the thermo-electric force of silicon steels reveals itself by curves of very uniform appearance, as shown in Figs. 18 and 19. It will be seen that it is considerably lowered, even more so than by nickel. This fact is particularly well brought out in the steels which contain low percentages of carbon.

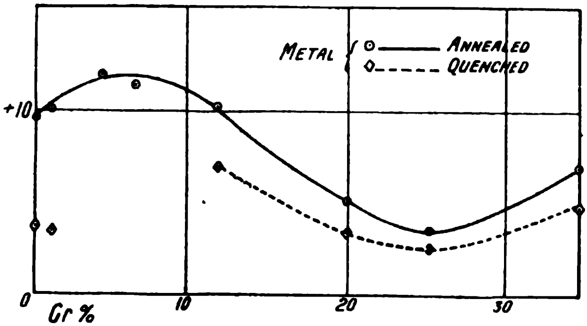

FIG. 12.—Chromium Steel with 0·8 per cent. Carbon, 80° − 0°.

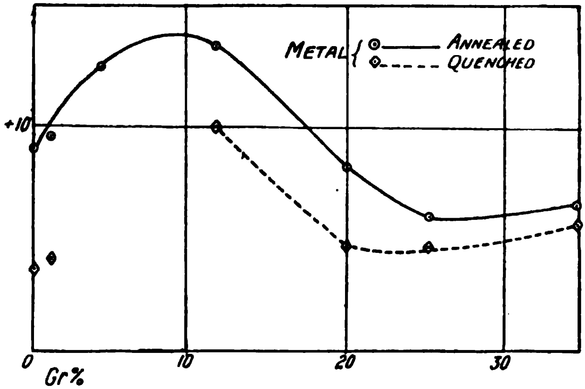

FIG. 13.—Chromium Steel with 0·8 per cent. Carbon, 0° + 100°.

The influence of quenching, which is negligible in the series containing 0·2 per cent. of carbon, is slightly marked in the carburised steels containing over 2 per cent. of silicon.

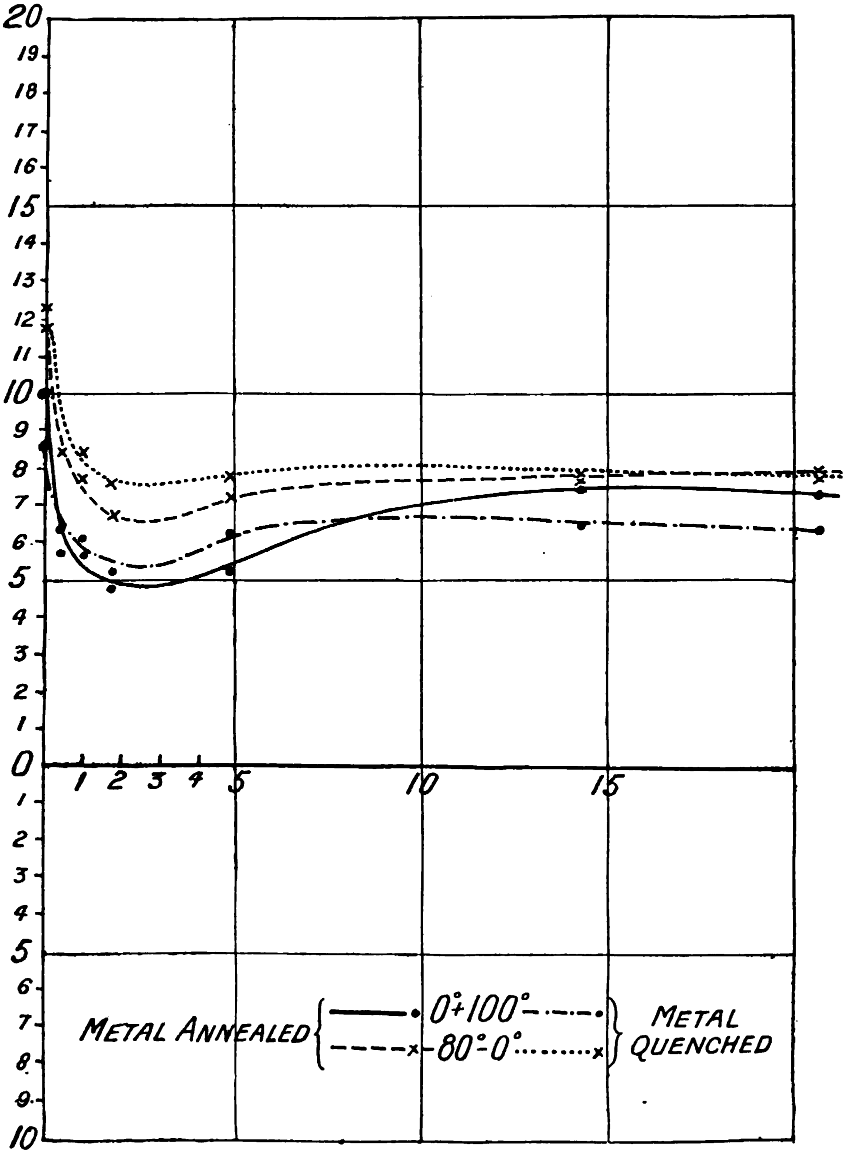

FIG. 14.—Tungsten Steels with 0·1 per cent. Carbon.

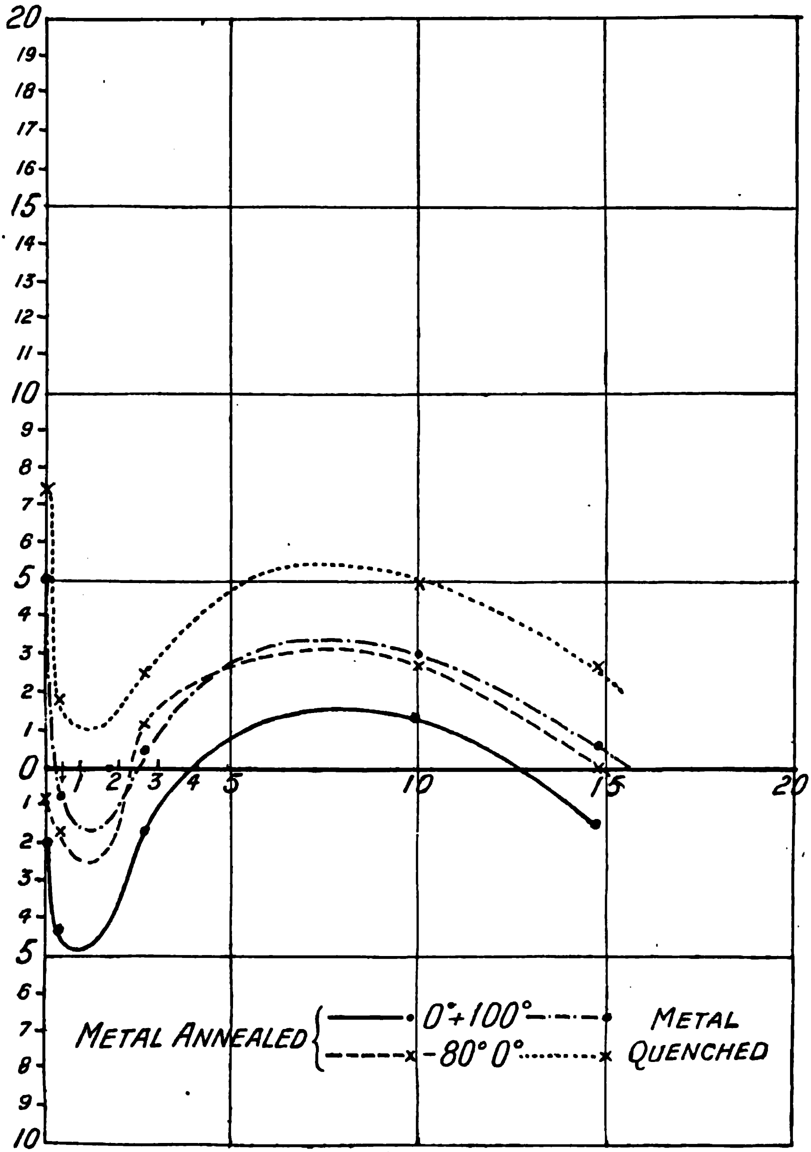

FIG. 15.—Tungsten Steels with 0·8 per cent. Carbon.

TABLE VIII.—*Silicon Steels.*

No.	Annealed.		Hardened.	
	-80°	+100°	-80°	+100°
1S0·5	+2·10	-0·30	+1·10	-0·90
1S1	-2·90	6·10	-1·30	5·00
1S2	4·80	8·28	5·00	8·40
1S3	6·80	10·80	6·90	10·40
8S1	-3·40	-6·00	Cracked	
8S2	6·80	9·90	-7·70	-10·20
8S3	8·20	12·00	8·90	10·70

TABLE IX.—*Aluminium Steels.*

No.	Annealed.		Hardened.	
	-80°	+100°	-80°	+100°
1A2	-7·50	-12·65	-8·10	-11·50
1A3	11·70	...	11·70	10·05
1A7	16·60	...	16·80	...
8A5	-10·00	-14·65	-13·60	-16·30
8A7	11·30	16·05	15·60	...
8A10	15·10	...	14·60	...
8A15	8·60	13·15	12·80	14·05

TABLE X.—*Manganese Steels.*

No.	Annealed.		Hardened.	
	-80°	+100°	-80°	+100°
8M0·5	-0·30	-3·10	0·00	-2·00
8M1	0·70	2·80	-5·40	6·65
8M3	2·60	4·70	Cracked	
8M12	9·60	11·80	10·00	...

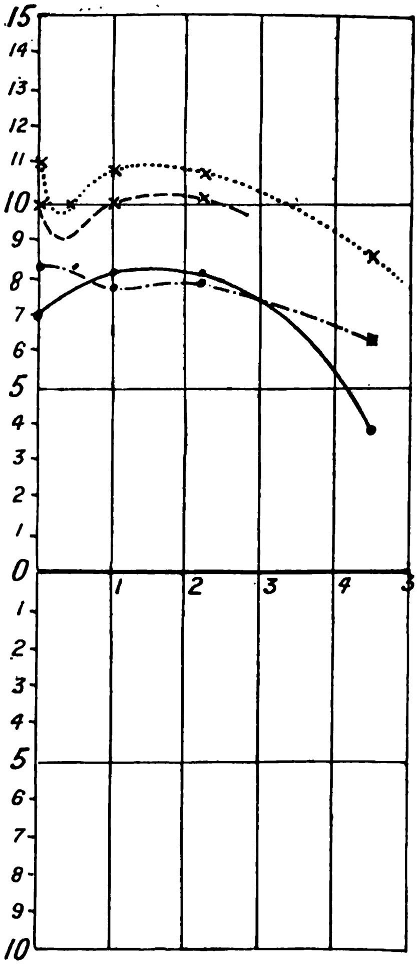

FIG. 16.—Molybdenum Steels with 0·1 per cent. Carbon.

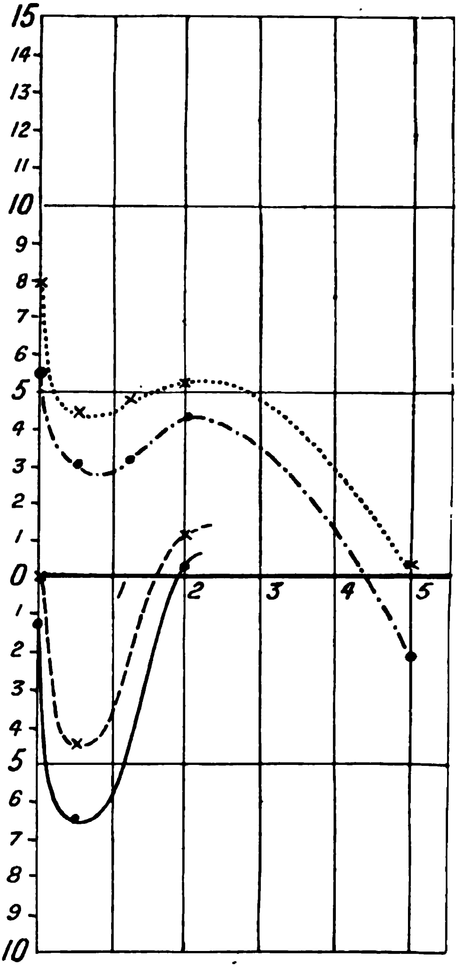

FIG. 17.—Molybdenum Steels with 0·8 per cent. Carbon.

Aluminium Steels (Table IX. and Figs. 20, 21).

The same statements may be made in regard to aluminium steels as in regard to silicon steels. The aluminium begins, indeed, by producing a considerable lowering of the thermo-electric power, the form of the curves being analogous with those furnished by the silicon steels.[1]

It would be easy to draw up an empirical parabolic formula

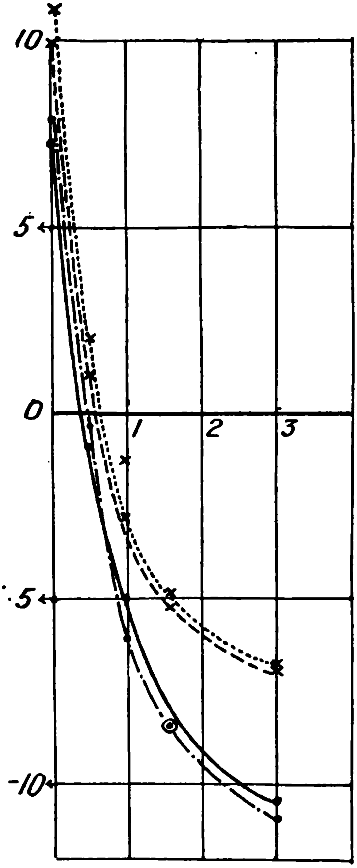

FIG. 18.—Silicon Steels with 0·2 per cent. Carbon.

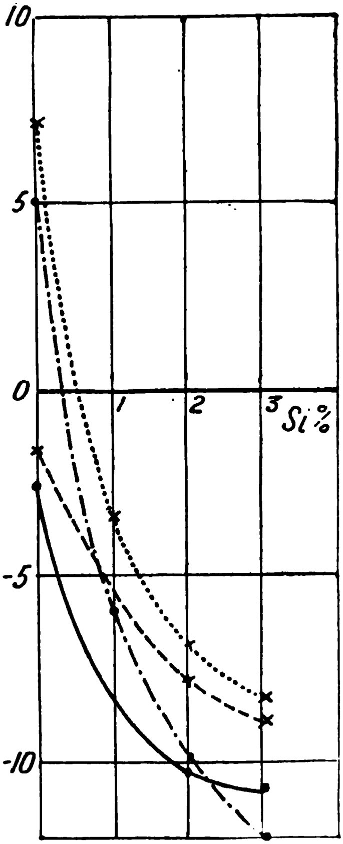

FIG. 19.—Silicon Steels with 0·8 per cent. Carbon.

representative of the thermo-electric force of silicon and aluminium steels, in the same way as one of the present authors has already done for the electrical resistance of aluminium steels.

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[1] In spite of the very small number of determinations, the authors have, nevertheless, plotted a curve for the series containing 0·8 per cent. of carbon, for the 0° to 100° interval, by letting themselves be guided by the appearance of the curve obtained for the same steels in the −80° to 0° interval.

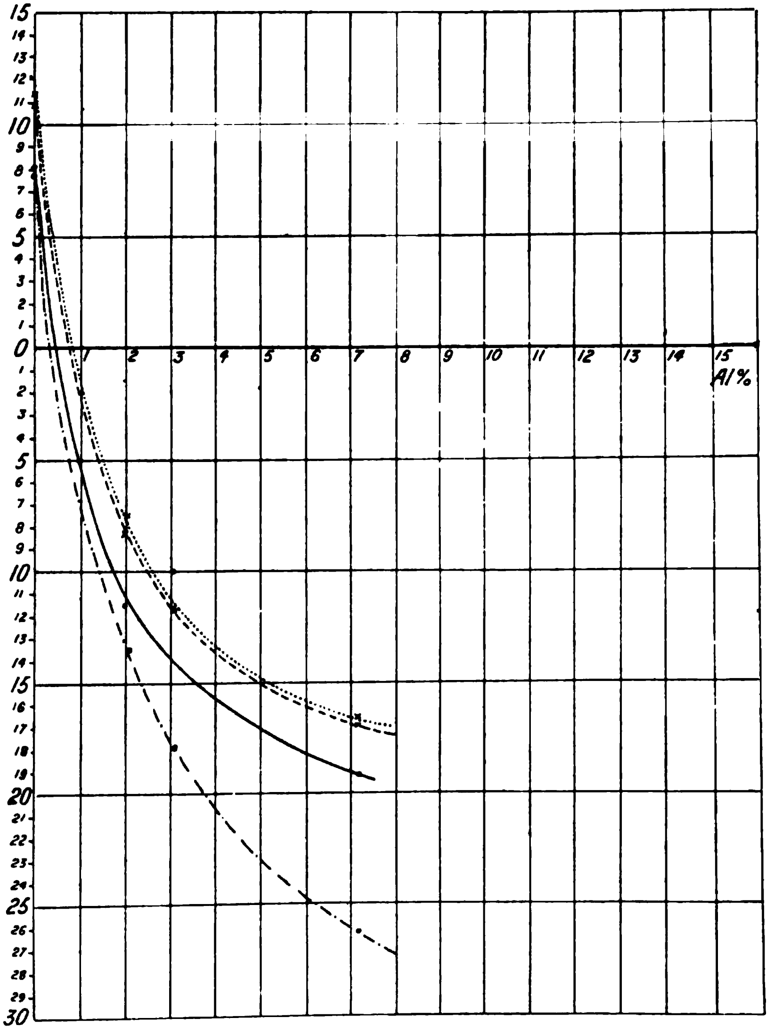

FIG. 20.—Aluminium Steels with 0·15 per cent. Carbon.

The influence of quenching is hardly appreciable in aluminium steels containing low percentages of carbon.

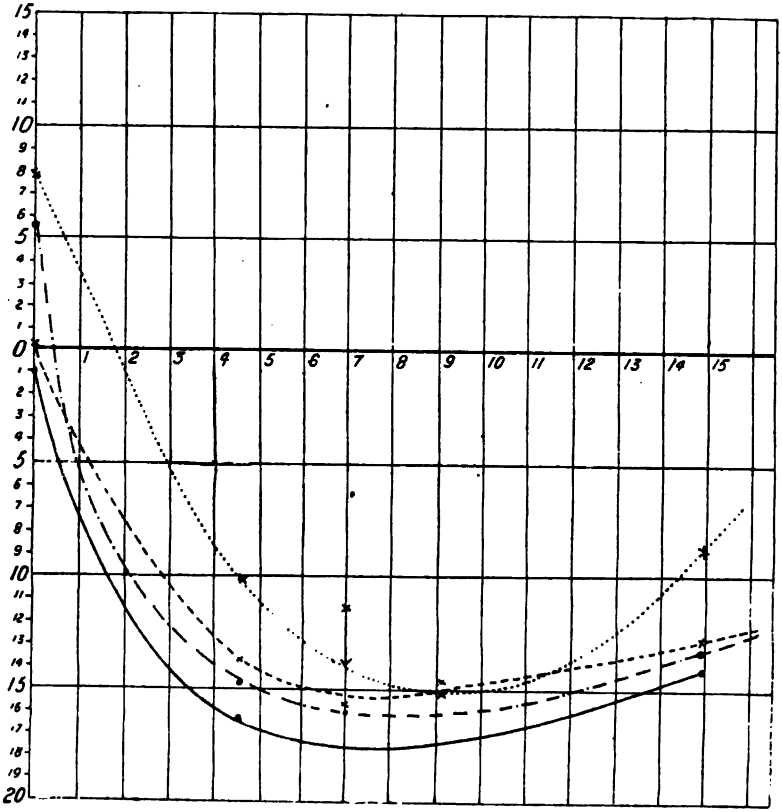

FIG. 21.—Aluminium Steels with 0·8 per cent. Carbon.

Manganese Steels (Table X. and Fig. 22).

There are only a very limited number of determinations available, and the curves of Fig. 22 are only submitted to the extent described. Their appearance is, moreover, exceedingly irregular. However, if in the results found for the interval − 80° to 0°, the allowance be made for the influence of the silicon, which may be done by employing the values given in Table VIII., the representative curve presents a remarkable degree of regularity. The latter curve might perhaps serve, in turn, for the rectification of the results obtained for the other steels, so as to help to eliminate the influence of their own percentages of manganese.

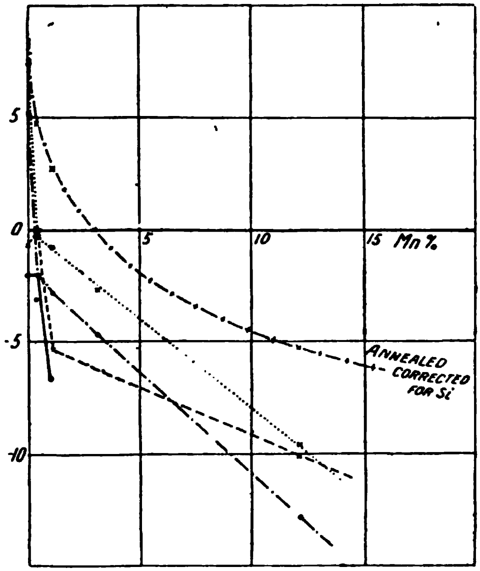

FIG. 22.—Manganese Steels.

CONCLUSIONS.

The curve representative of the thermo-electric force of an alloy, in terms of its composition, may assume the following forms:[1]

(1) In the case of a solid solution there will be a branch of the curve possessing the appearance of an arc of hyperbola, having its concave side turned either upwards or downwards.

(2) In the case of a mixture of two phases the curve is practically a straight line.

The thermo-electric force being capable of having a positive or negative sign, the definite compounds constituting solid solutions may be represented in the curves of thermo-electric force by maxima or minima, or, on the other hand, be situated along a branch in the form of an S, being marked only by a point of inflexion.

If, now, having recalled these governing principles, we consider the whole of the curves relating to thermo-electric force of the special steels which have been dealt with, it will be seen that from their general appearance they may be classified into two groups.

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[1] N. Toutourine, *Journ. Soc. Phys. Chim. Russe*, vol. xxvii. p. 1286 (1905); W. Broniewski, *R. de Métallurgie*, vol. vii. p. 341 (1910); Haken, *Annalen der Physik*, Series 4, vol. xxxii. p. 291 (1910).

(1) Special steels containing nickel, manganese, silicon, and aluminium, which give a continuous curve, which suddenly falls with great rapidity, and recalls the shape of a U, or of at least the first half of a U. From what has already been said, this appearance corresponds with that of solid solutions. The

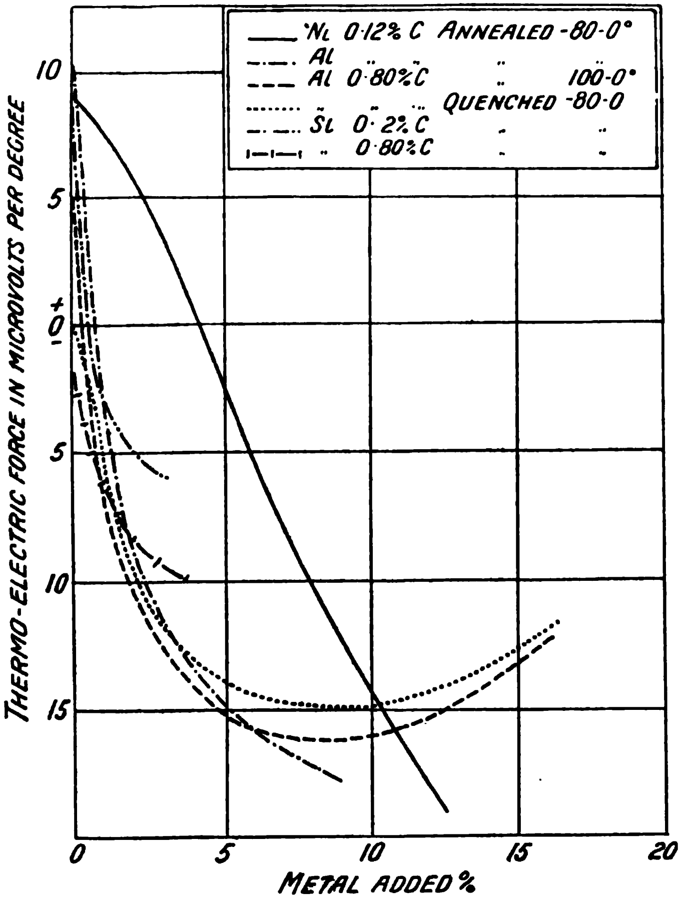

FIG. 23.—Steels with Solid Solutions.

metal added, so far, that is, as percentages within the range of the experiments extend, is therefore, in these instances, in the state of solid solution in the steel.

The authors have collated, in Fig. 23, the principal curves obtained, reduced to the same scale in order to bring this fact out in evidence.

(2) The special chromium, tungsten, and molybdenum steels, the curves of which begin with a sudden fall, indicate, as do those preceding, the passage of the metal into solid solution, followed by a rise, so that, taken as a whole, the curve resembles an S in form, as already pointed out.

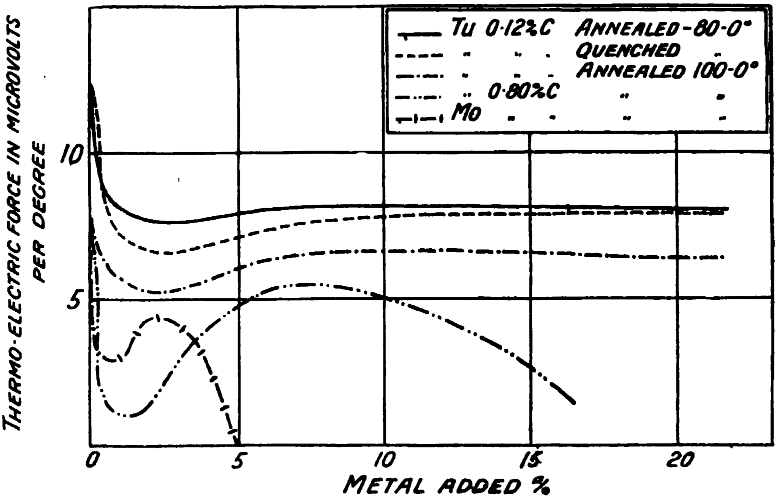

FIG. 24.—"Double Carbide" Steels.

This is shown in Fig. 24, which collates a certain number of the curves described in the foregoing.

Now these steels are those amongst which the class of steels known as "double carbide" occur. It is therefore possible, in this way, to form an idea as to the limit of solubility in the solid state of the special metals added to the steels, the carbide becoming isolated once saturation has been reached, either as a constituent of the pearlite or as a supereutectic constituent.

It may thus be seen, to begin with, how much interest attaches, from the point of view of their constitution, to the investigation of the thermo-electric force of the special steels, particularly so far as the existence and the condition of the double carbides are concerned.

If, as has been seen, the study of the thermo-electricity of the special steels allows, taken as a whole, of the drawing up of a system of general classification for some of these steels, the variations in this property are sufficiently marked and rapid enough to allow, if not of the actual quantitative estimation of the added element, at least of the obtaining of a substantial volume of additional information which will go far towards supplementing, with the happiest results, the details already furnished by the investigation of the other physical and mechanical properties.

THE CORROSION OF IRON IN AQUEOUS SOLUTIONS OF INORGANIC SALTS.

By J. NEWTON FRIEND, D.Sc. (Worcester)

AND

PETER C. BARNET, B.Sc. (Ryhope).

It is a matter of common knowledge that the presence of inorganic salts, dissolved in the water to which iron is exposed, exerts a profound influence upon the rate of corrosion of the metal. If the relative losses in weight of similar pieces of iron, exposed under uniform conditions to the action of solutions of varying concentrations of any one salt, are represented diagrammatically, as in Fig. 1, a number of very valuable observations may be made.

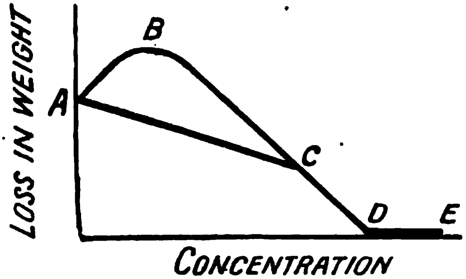

Fig. 1.—Typical Corrosion Curves.

Curve ABCDE may be regarded as typical for an ideal salt, point A representing the loss in weight of iron exposed to distilled water and air only. Addition of small quantities of the salt increases the corrosive action of the liquid until a maximum effect is reached at B. This is termed the "critical concentration." Further addition of the salt decreases the corrosivity of the solution until the point D is reached. From D to E (the saturation point) the solution inhibits corrosion.

D is termed the "limiting concentration." The researches of Heyn and Bauer[1] indicate that, at temperatures ranging from 16° to 22°, the following salts yield typical curves of this kind: Ammonium acetate; potassium bromate, carbonate, cyanide, ferri-cyanide, ferro-cyanide, iodate, and permanganate; di-sodium hydrogen phosphate; sodium carbonate and borate. In the case of potassium chlorate the points D and E appear to be approximately coincident. For the majority of salts, however, E lies to the left of D, at some such point as C; in other words, saturation is reached before inhibition, and the limiting concentration D is imaginary. A consideration of the curves shown in Figs. 2 to 14 will abundantly serve to illustrate this. Some salts apparently possess no critical concentrations. Potassium chromate and dichromate, and magnesium chloride at 11° C. (Fig. 6), yield curves of the type ACDE.

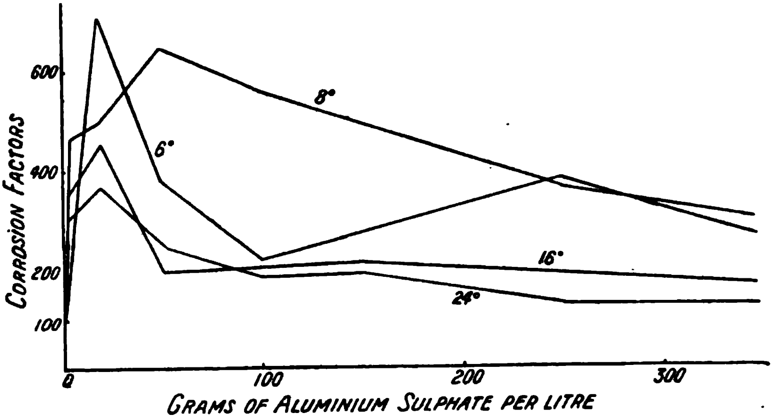

FIG. 2.

In most cases, however, saturation is reached before the limiting concentration and a curve of the type AC results. As will be seen later, it is always possible that even in these cases a critical concentration exists at some dilution intermediate between those experimented with, and that the true form of the curve is ABC.

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[1] *Mitteilungen aus dem königlichen Material-prüfungsamt*, 1908, vol. xxvi. p. 2.

In 1911 Friend and Brown[1] showed that, in the case of sodium chloride, the temperatures of the solutions during the experiments exerted a pronounced influence upon the kind of results obtained. Thus, whilst at 10° C. the critical solution was 20 per cent. more corrosive than distilled water, at 13° C. it possessed a corrosivity equal to distilled water, and at 23·5° a curve of the type AC was obtained (see Fig. 12). Thus, whilst in tropical climates salt solutions may be less corrosive than fresh water, in more temperate regions the reverse may be the case. The temperature at which a particular solution has the same corrosive action as distilled water may be termed the "inversion temperature" of that solution.

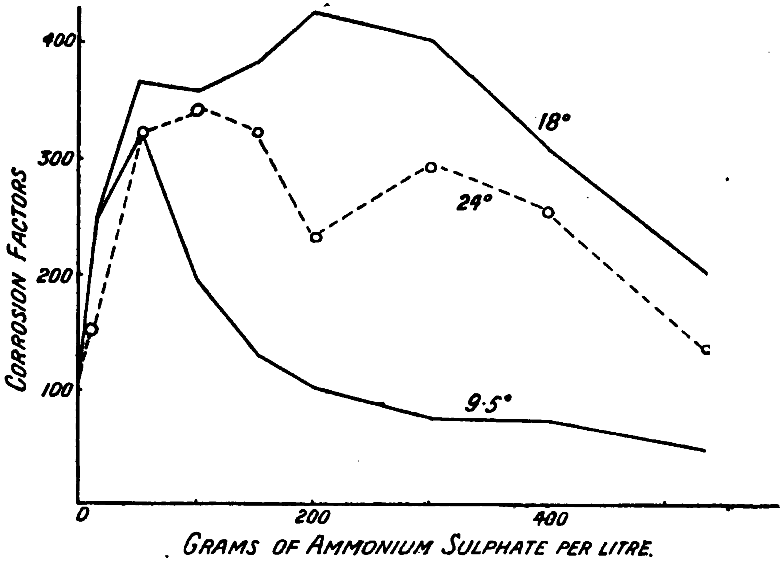

FIG. 3.

In view of the practical importance of these results, the authors have continued the study with various other solutions, at temperatures ranging from 3·5° C. to 24° C. Plates of Kahlbaum's pure electrolytic iron foil measuring 5 by 4 centimetres in area, and weighing approximately 2·2 grammes, were employed, being totally immersed in 100 cubic centimetres of solution contained in beakers or bottles. The plates rested with their four corners in contact with the sides and bottom of the containing vessel, the latter being kept in large thermostats. In the experiments at the lower temperatures the plates were exposed for fourteen days, but at higher temperatures the period of exposure was reduced to eleven or twelve days, in view of the increased rapidity of corrosion, in order that as nearly as possible corrosion should proceed to a comparable extent. At the conclusion of these experiments the plates were cleaned, and any loss in weight noted. The loss in weight of the metals in distilled water ranged from 0·02 to 0·04 gramme at the different temperatures. The chief difficulty in these experiments lay in obtaining complete series of regular results. To this end the solutions were prepared by dissolving the pure salts obtained from Kahlbaum in distilled water. The containing beakers were cleaned after each experiment, and fresh plates of iron were used, after

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[1] *Transactions of the Chemical Society*, 1911, vol. xcix. p. 1302.

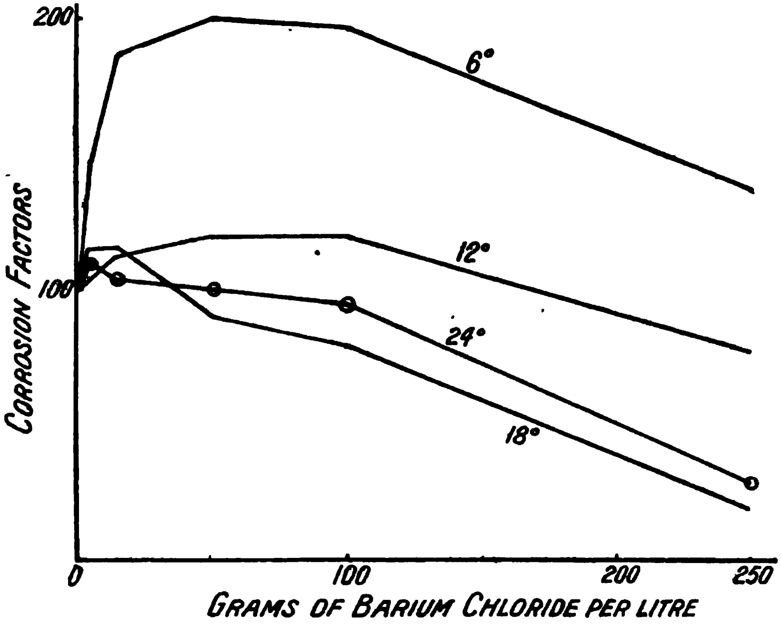

Fig. 4.

having been carefully polished with emery paper. Despite all these precautions some experiments were manifestly irregular, and proved incapable of repetition. This the authors attribute to some chemical or physical irregularity in the iron —a metal which it seems impossible to obtain in a sufficiently homogeneous condition.

In drawing their conclusions, therefore, they have been guided by the behaviour of the majority of the salts, rather than by any single one of them; and the irregularities observed in different series of experiments illustrate the danger of arguing from isolated results. The experiments in pure distilled water were always carried out in duplicate or triplicate for each series, because a determination of the extent of the corrosion in them is particularly important, inasmuch as they serve as standards in calculating the corrosion factors [1] for the rest of the series, the mean loss in weight of the plates being taken as 100. For the sake of easy comparison of the results obtained, the corrosion factors corresponding to the different temperatures are given only, and not the individual losses in

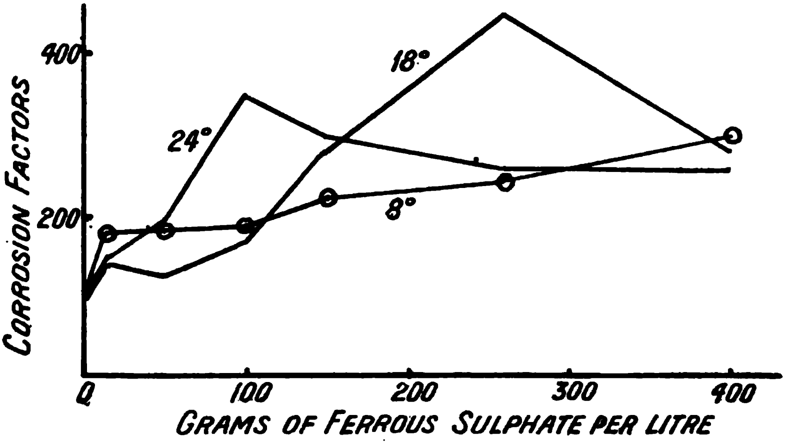

FIG. 5.

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[1] By corrosion factor is understood the corrosion of the iron in the salt solution relatively to that of the iron in the distilled water at the same temperature, the latter corrosion being taken as 100 in each series.

weight of the metals themselves. At the highest concentrations the solutions were always saturated, excess of the salt lying at the bottom of the containing vessels. The numerical value for the concentration is in these cases therefore only approximate, since the solubilities of the salts vary with the temperature.

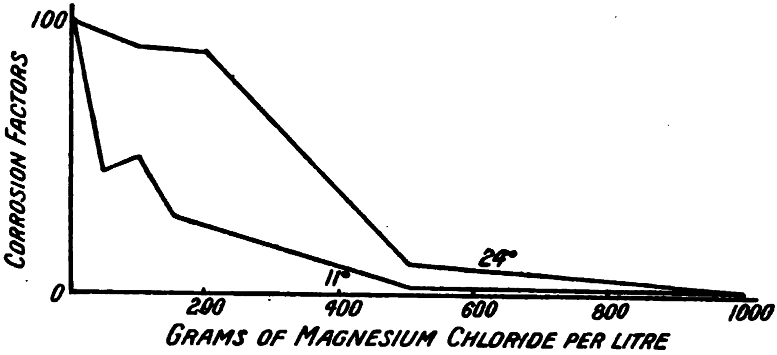

FIG. 6.

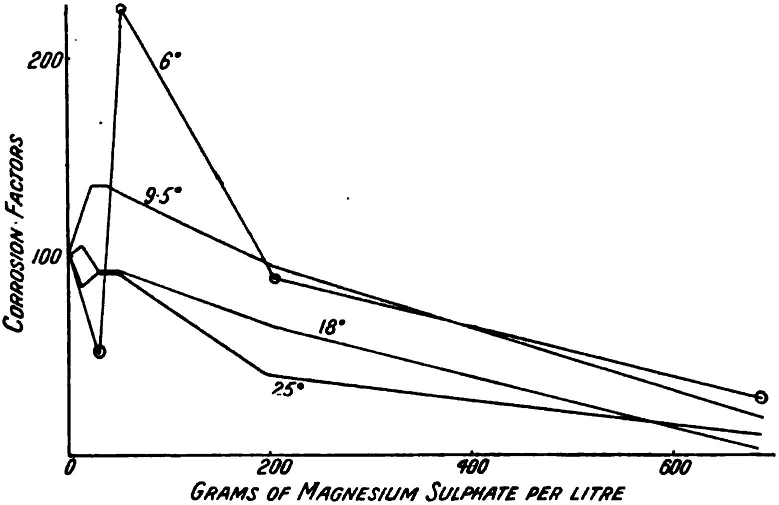

FIG. 7.

The results were as follows:—

Aluminium Sulphate ($Al_2(SO_4)_3,18H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	6.	8.	16.	18.	24.
0	100	100	100	100	100
1	170	162	146	141	127
5	110	462	337	354	296
20	700	491	452	586	364
50	375	639	197	318	244
100	210	554	190	254	178
150	240	504	205	218	179
250	360	346	166	289	108
360	250	287	149	296	82

Ammonium Sulphate ($(NH_4)_2SO_4$).

Concentration. Grammes per Litre.	Temperature, Degrees C.			
	6.	9·5	18.	24.
0	100	100	100	100
1	205	184	173	174
2	225	201	173	177
10	320	247	253	149
50	225	319	372	326
100	135	194	355	342
150	338	128	381	321
200	175	106	425	229
300	85	75	404	290
400	28	72	310	249
534	20	50	202	133

Barium Chloride ($BaCl_2,2H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	6.	12.	15.	18.	24.
0	100	100	100	100	100
1	...	...	87	83	94
5	147	105	111	120	110
15	187	113	121	120	105
50	199	119	111	90	100
100	196	119	62	79	95
250	138	78	30	37	29

Ferrous Sulphate ($FeSO_4,7H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.			
	4·5.	8.	18.	24.
0	100	100	100	100
1	109	108	145	141
5	114	137	142	132
15	85	177	144	154
50	139	188	129	192
100	179	187	168	350
150	239	225	286	300
260	268	246	447	261
400	358	300	275	258

Magnesium Chloride ($MgCl_2,6H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.	
	11.	24.
0	100	100
1	72	95
10	72	97
50	45	91
100	51	87
150	27	87
200	...	78
500	3	23
1000	1	0

Magnesium Sulphate ($MgSO_4,7H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	6.	9·5	15.	18.	23.5
0	100	100	100	100	100
1	105	72	83	95	79
2	65	90	84	112	73
10	60	115	114	104	79
25	50	133	116	93	91
50	225	137	105	90	88
200	65	87	54	59	39
700	30	22	38	3	8

Manganese Sulphate ($MnSO_4,5H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.			
	4·5.	11.	18.	23·5.
0	100	100	100	100
0·1	85	84	117	109
0·5	85	48	113	97
2	65	30	117	97
10	49	30	113	88
100	97	30	90	64
800	65	27	57	24

Potassium Chloride (KCl).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	3·5.	10.	15.	18.	23.
0	100	100	100	100	100
5	163	102	137	109	118
15	183	100	149	122	104
50	290	107	155	68	85
150	143	86	88	54	57
300	30	29	16	24	28

Potassium Nitrate (KNO_3).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	5.	9·5.	13·5.	18.	23.
0	100	100	100	100	100
1	210	180	172	197	154
5	266	198	183	164	121
15	283	216	183	143	121
50	289	236	210	169	112
150	120	76	133	140	105
240	227	45	114	30	70

Potassium Sulphate (K_2SO_4).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	6.	**10.**	**15.**	**18.**	**23·5.**
0	100	100	100	100	100
1	...	...	84	98	108
5	187	105	70	117	105
10	189	90	115	129	101
15	182	95	120	122	94
50	191	76	23	79	85
100	77	67	14	20	36

Sodium Chloride (NaCl).

Concentration. Grammes per Litre.	Temperature, Degrees C.			
	10.[1]	**13.**[1]	**21.**[1]	**23·5.**
0	100	100	100	100
1	...	...	...	102
5	111	93	86	91
10	110	97	84	94
15	105	95	74	95
30	120	96	68	81
60	94	98	61	76
120	72	72	40	60
400	...	...	...	8

Sodium Nitrate ($NaNO_3$).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	5.	**9·5.**	**13·5.**	**18.**	**23·5.**
0	100	100	100	100	100
1	205	209	171	184	112
5	233	228	295	165	121
15	264	222	203	171	137
50	278	224	207	220	147
150	205	148	134	132	56
800	8	11	3	35	11

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[1] See Friend and Brown, *Transactions of the Chemical Society*, 1911, vol. xcix. p. 1302.

Sodium Sulphate ($Na_2SO_4,10H_2O$).

Concentration. Grammes per Litre.	Temperature, Degrees C.				
	3·5	12.	15.	18.	23.
0	100	100	100	100	100
5	173	119	112	109	102
15	190	109	163	111	100
50	237	97	161	123	109
100	183	108	59	90	85
200	177	60	35	84	61
300	153	47	23	51	46

Consideration of the foregoing results reveals several interesting facts.

1. Concentrated solutions of the majority of the salts experimented with are less corrosive than distilled water, the exceptions being ammonium sulphate above 9·5° C., aluminium sulphate below 24° C., ferrous sulphate, and (at temperatures of and below 6°) sodium sulphate, potassium nitrate, and barium chloride. The results for magnesium chloride are particularly interesting in view of the general belief in the corrosive action of the salt; they agree reasonably well with the results obtained by Heyn and Bauer,[1] Friend and Brown,[2] and more recently by Bradley[3] and Howell.[4]

2. As the temperature rises the absolute corrosion in unit time increases rapidly, but, as a general rule, the corrosive power of the salt solutions in each series decreases relatively to that of distilled water; in other words, the corrosion factors fall with rise of temperature. Ammonium sulphate appears to be exceptional, but this is probably due to hydrolysis. The results for manganese sulphate, sodium sulphate, and potassium sulphate, and chloride at 10° to 12° are likewise abnormal, but for what reason is not clear.

3. It seems reasonable to assume that every concentration of a salt solution that can induce corrosion has its own

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[1] *Loc. cit.*

[2] *Journal of the Iron and Steel Institute*, 1911, No. I. p. 125.

[3] *Chemical News*, 1913, vol. cviii. p. 307.

[4] *Proceedings of the Institution of Civil Engineers*, 1913–1914, vol. cxcvi., Paper No. 4076.

inversion temperature. Possibly in some cases this may not be experimentally attainable, as the solution may freeze before a sufficiently low temperature is reached. Further research, however, is needed on this point.

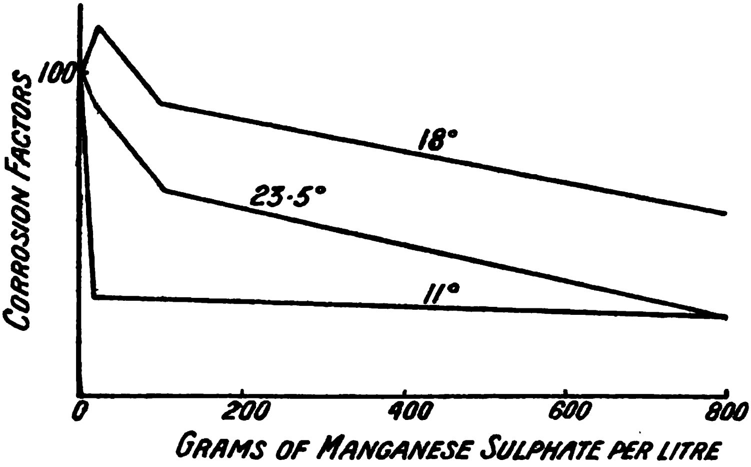

FIG. 8.

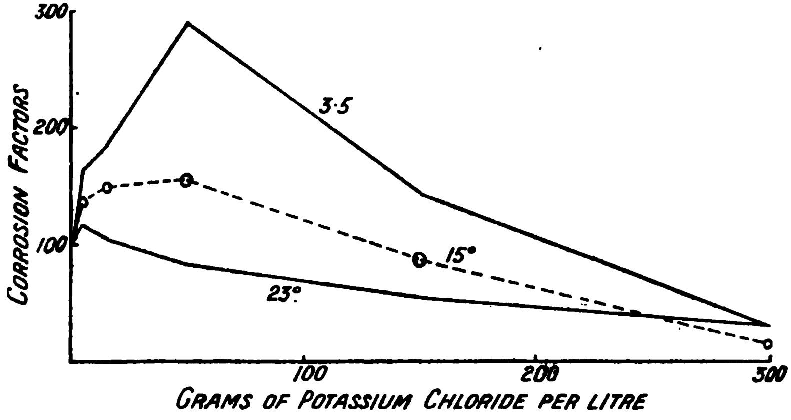

FIG. 9.

4. The more concentrated the solution of any salt the lower its inversion temperature, in general, and conversely. This is illustrated by the following table, in which are given

the approximate inversion temperatures of a few of the salt solutions experimented upon, as calculated from the data given in the tables on pages 342–346:—

Rise of Inversion Temperature with Fall of Concentration.

Salt.	Concentration. Grammes per Litre.	Inversion Temperature. Degrees C.
Barium chloride ($BaCl_2,2H_2O$)	348[1]	6
	70	12
	61	15
	50	24
Magnesium sulphate ($MgSO_4,7H_2O$) . .	167	6
	161	9·5
	65	15
	15·5	18
Potassium chloride (KCl)	206	3·5
	132	15
	83	10
	29	18
	22	23
Sodium nitrate ($NaNO_3$)	496	5
	377	9·5
	365	18
	319	13·5
	102	23·5
Sodium sulphate ($Na_2SO_4,10H_2O$)	100	12
	85	18
	80	15
	15	23

5. The concentration of the critical solution[2] tends to fall with rise of temperature. This is well shown in the case of barium chloride, ferrous sulphate, magnesium sulphate, potassium chloride, and nitrate (see following Table and Figs. 4, 5, 7, 9, and 10), but is less apparent with some of the other salts, such as sodium nitrate (Fig. 13), which probably owes its irregular action to its power of oxidising iron. The above observation is important because it indicates that at high temperatures, such as the boiling point of water, the presence of small quantities of dissolved impurities may exert a far more serious corrosive action upon iron than experiments at

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[1] Hypothetical. The solution is saturated at 6° with 250 grammes of $BaCl_2,2H_2O$.

[2] Given in black type in the tables.

ordinary temperatures would lead us to expect. Further research on this point is eminently desirable to throw light upon the corrosion of boilers, &c., by impure feed water.

In many of the solutions the inversion temperatures of the critical solutions clearly lie above 23°. This is the case with potassium nitrate and chloride, sodium nitrate and sulphate, and with ferrous, aluminium, and ammonium sulphates. Heyn and Bauer's experiments appeared to indicate that the inversion temperatures of critical solutions of potassium chloride and sodium sulphate are lower than 18°, since at this temperature the corrosion curve was of the type AE (Fig. 1). This difference might be due either to the fact that these investigators used a commercial wrought iron in their experiments, or to a difference in the method of experi-

Fall of Critical Concentration with Rise of Temperature.

Salt.	Temperature. Degrees C.	Critical Concentration. Grammes per Litre.
Barium chloride ($BaCl_2,2H_2O$)	6	50
	12	50
	15	15
	18	5
	24	5
Iron sulphate ($FeSO_4,7H_2O$)	8	400
	16	400
	18	260
	24	100
Magnesium sulphate ($MgSO_4,7H_2O$)	6	50
	9·5	50
	15	25
	18	2
	23·5	0
Potassium chloride (KCl)	3·5	50
	10	50
	15	15
	18	15
	23	5
Potassium nitrate (KNO_3)	5	50
	9·5	50
	13·5	15
	18	1
	23	1

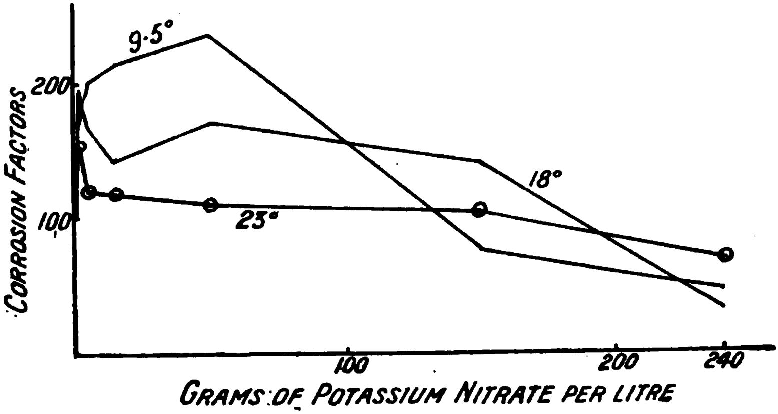

FIG. 10.

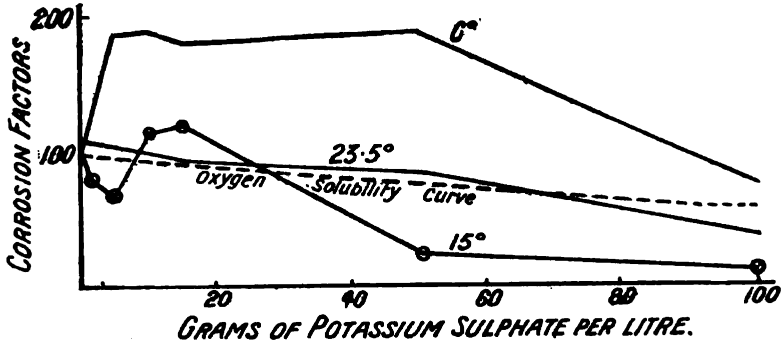

FIG. 11.

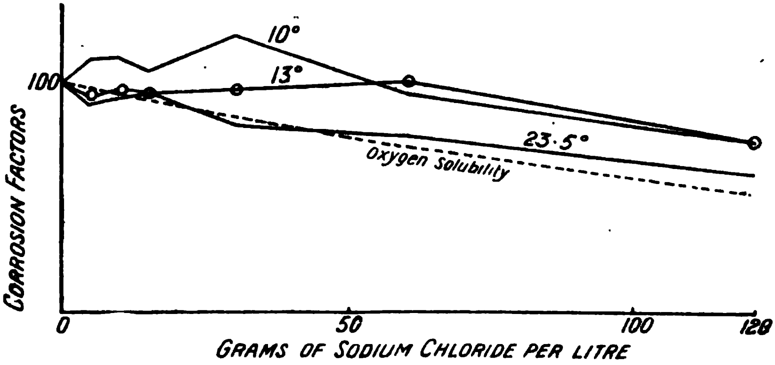

FIG. 12.

mentation; but another very plausible explanation is possible. As has been already mentioned, the concentration of the critical solution exhibits a tendency to fall with rise of temperature. If now, at any particular temperature, the true critical concentration happens to lie midway between the two consecutive concentrations chosen in the series of experiments, it may be altogether missed, whilst the apparent

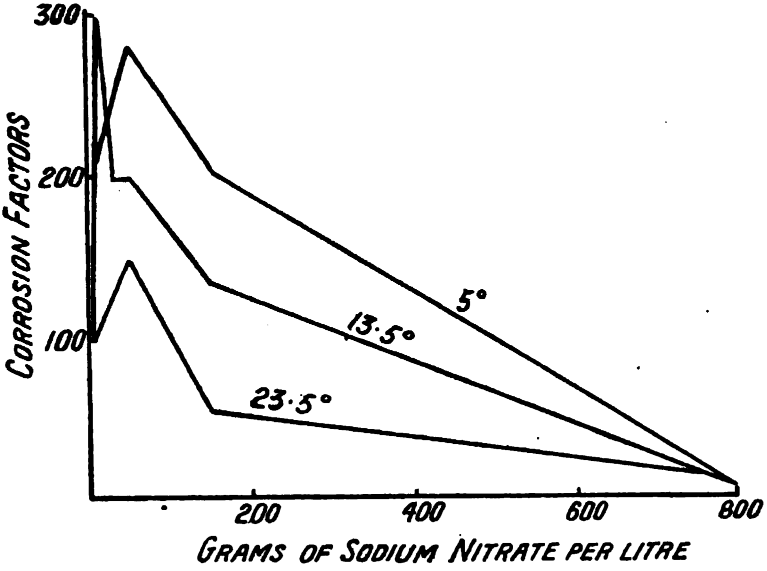

FIG. 13.

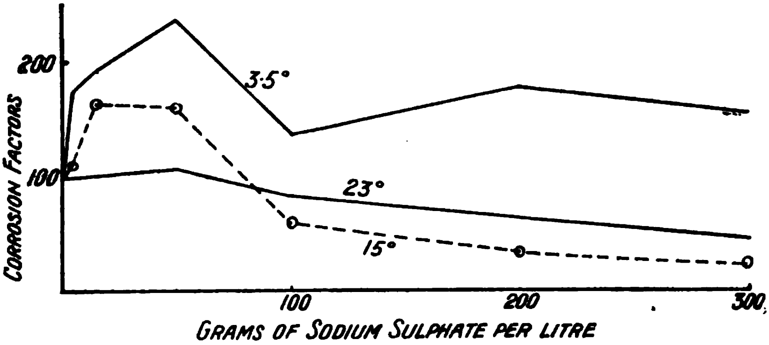

FIG. 14.

critical solution is at or near its inversion temperature. Possibly this accounts also for the absence of critical concentrations for solutions of magnesium chloride at 11° and 24° (Fig. 6), of manganese sulphate at 11° (Fig. 8), and of sodium chloride at 13° and 21°.

The authors make no attempt at this stage of their work to offer an explanation for these results. The close connection between ionisation and corrosion has already been noted,[1] and there can be no doubt that the solubility of oxygen in the solutions (see Figs. 11 and 12),[2] and the chemical action of the salts upon the surface of the iron, such as the passivifying action of nitrates, &c., are also important factors in determining the extent of corrosion. In theorising, therefore, each of these factors must be taken into account, and at present all the necessary data have not been acquired.

The authors desire to thank the Research Fund Committee of the Chemical Society for a grant that has defrayed the greater part of the expense entailed by this research.

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[1] Friend and Marshall, *Transactions of the Chemical Society*, 1914, vol. cv. p. 2776.

[2] The solubilities of oxygen in these salt solutions are indicated by the broken lines, the solubility in distilled water being taken as 100, the other solubilities being expressed relatively thereto for convenience of comparison with the corrosion factors.

THE RELATIVE CORRODIBILITIES OF GREY CAST IRON AND STEEL.

WITH A NOTE ON THE REMOVAL OF RUST BY MEANS OF CHEMICAL REAGENTS.

BY J. NEWTON FRIEND AND C. W. MARSHALL (WORCESTER).

COMPARATIVELY little work has been done within the last decade on the relative corrodibilities of cast iron, wrought iron, and steel. The earlier researches are now of considerably less practical value than formerly, in view of the great changes that have taken place in the methods of manufacture, accompanied, of necessity, by changes in the physical and chemical properties of the metals. The most recent researches are those of Arndt and of Wölbling, who have independently compared the corrodibilities of cast irons and mild steels, both on exposure to moist air and during prolonged immersion in wet sand. The rate of corrosion was determined by measuring the volumes of oxygen absorbed. In wet sand the steel was observed to be more resistant to corrosion than cast iron,[1] the reverse being the case in moist air.[2] It was only to be expected, in view of the complex nature of cast iron, that the relative corrodibilities of that metal and steel would vary very considerably with the nature of the corroding medium, and the present research was undertaken in order to throw light on this point. To this end a typical grey cast iron[3] and a mild open-hearth steel were chosen, the metals being cut into square bars measuring 4·5 × 1 × 1 centimetres, and weighing approximately 30 grammes. After removing the surface skin on the emery-wheel, the following tests were made:—

1. *Tap-water Tests.*—The weighed samples resting on plates of paraffin wax were laid in beakers containing 300 cubic centimetres of tap water, and placed in a dark cupboard.

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[1] Arndt, *Metallurgie*, 1911, No. 8, p. 353; Wölbling, *Ferrum*, 1913, No. 10, p. 161.

[2] Arndt, *Chem. Zeitung*, 1910, No. 34, pp. 425, 1078; Wölbling, *loc. cit.*

[3] Kindly supplied by Mr. W. B. Greener, manager of Messrs. Green & Co., Economiser Works, Wakefield, to whom the authors take this opportunity of recording their thanks.

After three months the metals were removed, scraped clean, dried in a steam-oven and weighed, the loss in weight being taken as a measure of corrosion.

2. *Salt-water Tests.*—These were carried out in a manner exactly similar to the tap-water tests, save that the corroding medium was a 3 per cent. solution of sodium chloride.

3. *Alternate Wet and Dry Tests.*—These were carried out in a large metal bath, the metals lying upon a paraffin sheet, and alternately covered with water and allowed to drain, as described in a previous paper.[1]

4. *Alternate Wet and Dry and Hot and Cold Tests.*—These tests consisted in subjecting the samples to wet and dry, as in the previous case, but during the daytime the bath was heated to about 80° C., and allowed to cool at night. The corrosion was relatively very rapid. The metals were laid on plates of glass, paraffin being inadmissible on account of its low melting-point.

5. *Alternate Hot and Cold Tests.*—These consisted in completely submerging the metals on glass plates in a trough of water, heating to boiling during the daytime, and allowing to cool at night.

6. *Acid Tests.*—These tests resembled tap-water tests, save that the corroding medium was dilute sulphuric acid, which was frequently renewed with the two lowest concentrations. The concentrations of the acid employed were as follows: 0·05, 0·5, 5,[2] 10,[2] and 20 [2] per cent. respectively. Prior to drying in the steam-oven the metals were rinsed in dilute caustic potash solution. This, by neutralising any traces of free acid remaining in the pores of the metal, prevented further corrosion during drying.

The results obtained are given in the accompanying table.

Analyses of Metals Used.

Steel—	Per Cent.
Combined carbon	0·21
Silicon	0·013
Manganese	0·49
Sulphur	0·026
Phosphorus	0·053

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[1] *Journal of the Iron and Steel Institute*, 1912, No. I. p. 253.

[2] 350 cubic centimetres of acid were used in these experiments.

TABLE I.

No.	Corroding Medium.	Duration of Test.	Steel.			Cast Iron.		
			Loss in Weight. Grammes.	Mean.	Corrosion Factor.	Loss in Weight. Grammes.	Mean.	Corrosion Factor.
1	Tap-water	3 months	0·1912 0·1860	0·1886	100	0·2210 0·2206	0·2208	117
2	do.	do.	0·1838 0·1972	0·1905	100	0·1950 0·2010	0·1980	104
3	Salt-water (3 per cent.)	do.	0·1958 0·1976	0·1967	100	0·1866 0·1846	0·1856	94
4	do.	do.	0·2006 0·2250	0·2128	100	0·1844 0·1972	0·1908	90
5	Alternate wet and dry	2 months	0·4032 0·3138	0·3585	100	0·2914 0·2884	0·2899	81
6	do.	3 months	0·2174 0·2732 0·2450 0·2766	0·2543	100	0·2560 0·2316 0·2750 0·2586	0·2553	100
7	Alternate hot & cold water	11 weeks	0·2178 0·2106	0·2142	100	0·2174	0·2174	101
8	Alternate hot and cold and wet and dry	6 weeks	0·2800 0·2290	0·2545	100	0·1798 0·1804	0·1801	71
9	0·05 per cent. sulphuric acid	do.	0·4418 0·4324	0·4371	100	0·4790 0·4916	0·4853	111
10	0·5 per cent. do.	do.	4·3260 4·3364	4·3312	100	5·0516 5·2170	5·1343	119
11	5 per cent. do.	3 hours	0·0800 0·0794	0·0797	100	0·3114 0·3228	0·3171	398
12	5 per cent. do.	16 hours	0·4518 0·2866	0·3692	100	2·0436 1·9286	1·9861	538
13	10 per cent. do.	3 hours	0·1466 0·1399	0·1433	100	0·5168 0·5022	0·5095	355
14	10 per cent. do.	16 hours	0·9608 0·9004	0·9306	100	2·0680 2·1058	2·0869	224
15	20 per cent. do.	3 hours	0·2722 0·2632	0·2677	100	0·7082 0·7124	0·7103	265

Cast iron—	
Graphite	2·75
Combined carbon	0·61
Silicon	1·72
Manganese	0·75
Sulphur	0·085
Phosphorus	1·06

CONSIDERATION OF THE RESULTS.

In considering these results it is important to bear in mind that, strictly speaking, they apply only to the particular metals tested, and that their application to the behaviour of cast iron and steel generally depends upon whether or not these samples are truly representative. The authors believe they are, because the results agree, in so far as comparison is possible, with the data published by Arndt and Wölbling. They are also in general harmony with the data given by Thwaite in 1880[1] and by Grüner in 1883,[2] which seems to suggest that the relative corrodibilities of cast iron and steel bear much the same relation to one another at the present time as in earlier years, despite the alteration in methods of manufacture.

The following observations suggest themselves as particularly important:—

1. In the alternate wet and dry tests, whether carried out at room temperature or alternately heated and cooled, the cast iron usually had the decided advantage.

In experiment No. 6 the flow of water was unavoidably stopped for a week or two, with the result that the rust caked on to the metals, was very difficult to remove, and appears to have exerted a marked protecting influence against further corrosion. Experiments Nos. 5 and 8, however, proceeded uniformly throughout their duration. The alternate wet and dry tests probably reproduce, as nearly as can be done in a laboratory, the corrosive forces involved in exposure of iron to the action of the outside air in practice. These experiments thus appear to indicate that in ordinary cases of exposure cast iron articles would last longer than steel ones—and this is usually found to be the case in practice.

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[1] Thwaite, *Journal of the Iron and Steel Institute*, 1880, No. II. p. 667.

[2] Grüner, *Comptes rendus*, 1883, No. 96, p. 195.

2. Complete immersion of the metals in water does not give quite the same results as the alternate wet and dry tests, there being now little to choose between the cast iron and steel. (Experiments Nos. 1, 2, and 7.) If there is any advantage it appears to lean towards the steel.

3. The cast iron appears to have a slight advantage over the steel in salt water.

4. In acid solutions the cast iron was very badly attacked, the steel proving in comparison highly resistant. The variation of the results with time and concentration of acid is noteworthy, constituting a remarkable testimony not merely to the uselessness, but to the actually misleading nature of acid acceleration tests, when used as a rapid means of determining the general corrodibility of iron and steel.

CONCLUSION.

From these results it is abundantly evident that no simple answer can be given to the oft-repeated question, "Which is the more corrodible, cast iron or steel?" unless full details are given as to the nature of the corroding media.

In ordinary air grey cast iron would appear to be more resistant to corrosion than steel. When completely submerged in water there is very little to choose between the two metals. In regard to resistance to sulphuric acid attack, the steel has the decided advantage.

In conclusion the authors desire to thank the Research Fund of the Chemical Society for a grant which has defrayed part of the expenses entailed in this work.

NOTE ON THE REMOVAL OF RUST BY MEANS OF CHEMICAL REAGENTS.

For many purposes of both technical and purely scientific importance it is eminently desirable to find some method or chemical reagent that will readily remove rust from iron.

In many cases, as, for example, in cleaning structural steel work prior to painting, the loss of a little iron along with the rust is not a matter of serious moment. In the cleansing of museum specimens, particularly when attempts are made to read partially obliterated inscriptions, it is important to lose as little iron as possible; whilst in scientific investigations, which have for their object the quantitative determination of corrosion by weighing the iron before and after attack, it is essential that the loss of unoxidised metal involved in removing the rust shall be reduced to the absolute minimum.

Electrochemical methods have frequently been suggested, the rusty iron being suspended as cathode in a suitable electrolyte, the anode consisting of some inert material, such as carbon or platinum. By adjusting the current density, the hydrogen set free at the cathode appears to loosen the rust[1] by what is asserted to be a purely mechanical process, not involving the solution of any iron, and for such processes considerable accuracy is claimed. Scraping with knives and polishing with sand- or emery-paper has been the process adopted for small specimens by the present authors in their hitherto published researches, and the method has proved perfectly satisfactory. But for large test-pieces, such as plates measuring 1 or 2 square feet in area, the scraping process is very disagreeable and fatiguing. In the literature on this subject different investigators have frequently alluded to dilute solutions of sodium citrate as suitable media for loosening rust *without dissolving any iron.* It seemed desirable, therefore, to test this assertion by a series of quantitative experiments with rusty plates, and to extend the inquiry to the action of other chemical reagents upon rusty iron.

METHOD OF EXPERIMENT.

It is not an easy matter to obtain a large number of small plates rusted evenly over their surfaces and to an equal quantitative extent, such as is required for the present investigation. The metal ultimately chosen consisted of mild open-hearth steel sheets, cold rolled and charcoal annealed, measuring 2 by

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[1] See Jacob and Kaesbohrer, *Chemiker Zeitung*, 1911, vol. xxxv. p. 877.

1 feet in area, and 22 B.W.G. in thickness. Several of these sheets were soaked in water and exposed to the air for a month, after which they appeared to be corroded fairly equally over their surfaces. They were then cut up into squares, measuring 2¼ by 2¼ inches, and weighing approximately 19 grammes. In order further to insure uniformity, results obtained with the small plates were only compared with one another when they had been cut from the same large sheet. The plates contained approximately 0·2 gramme of hydrated ferric oxide, in which was only the merest trace of ferrous iron. Several of the plates were thoroughly cleaned with emery-paper, the mean losses in weight being taken as standards for comparison with the results obtained by chemical means. As an example of the degree of accuracy that may reasonably be expected, the following losses of weight of small plates cut from the same sheet may be quoted:—

	Sheet 1.	Sheet 2.
	Gramme.	Gramme.
Plate 1	0·2495	0·1772
Plate 2	0·2347	0·1682
Plate 3	0·2336	0·1718
Plate 4	0·2398	0·1628
Mean	0·2394	0·1700

The extreme values for plates cut from sheet 1 differ from each other by 6·4 per cent., whilst for sheet 2 the difference is 11·3 per cent. These variations suffice to show how important it is to repeat all experiments a considerable number of times in order to insure that no effect of importance is either caused or masked by any eccentricity of the metal.

The plates, except where otherwise stated, rested on paraffin sheets in an inclined position in beakers of 450 cubic centimetres capacity, and exposed to diffused daylight at a temperature of approximately 15° C. At stated intervals the plates were removed, scrubbed with a small brush under the tap, wiped and dried with filter-paper, the last traces of moisture being removed prior to weighing by gently warming near a boiler. After immersion in acid solutions, the plates invariably tarnished during drying, if treated in this way, but that was obviated by dipping into dilute caustic potash solution for a moment or two after scrubbing, in order to neutralise any traces of acid remaining in the pores of the metal.[1]

Sodium Citrate.

Five different concentrations of sodium citrate were used, namely, 1, 2, 5, 10, and 20 per cent., with the following results:—

Days.	Loss in Weight of Rusty Plates.				
	1	2	3	4	5
	Gramme.	Gramme.	Gramme.	Gramme.	Gramme.
3	0·1248	0·1576	0·2266	0·2770	0·3810[2]
4	0·1746	0·2100	0·2718	0·3260	**0·4326**[3]
5	0·2110	0·2334	0·2904	0·3376	**0·4574**
6	0·2412	0·2534	0·3218	0·3714	**0·4764**
7	0·2942	0·2738	0·3474	0·3874	**0·5048**
8	0·3802	0·3160	0·4146	**0·4258**	**0·5598**
Sodium citrate . . .	1 per cent.	2 per cent.	5 per cent.	10 per cent.	20 per cent.

These results are shown graphically in Fig. 1.

The mean weight of rust removed by mechanical means from similar plates of rusty iron was 0·2085 gramme.

After six days the plate immersed in the 1 per cent. solution appeared to begin rusting on its own account. After eight days the first three plates were black in appearance, but turned brown on drying; plate 4 was fairly clean; and plate 5, in the 20 per cent. solution, remained perfectly clean after the first four days, the metal presenting a beautiful surface. During cleaning it lost in weight practically 100 per cent. more than the mechanically cleaned plates, and the iron continued to dissolve during the whole period of immersion. It is interesting to note that the fourth plate became almost clean in eight days, after it had lost in weight an amount practically equal to that lost by plate 5 when clean.

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[1] See Friend, *Transactions of the Chemical Society*, 1912, vol. ci. p. 50.

[2] One side clean on scrubbing.

[3] Both sides clean. The stages at which the irons were clean on scrubbing are shown in dark type in this and in all succeeding tables.

From these results it is evident that solutions of sodium citrate are not suitable media for investigations involving the quantitative removal of rust. Also they are extremely slow in their action, as is evident from the curves (Fig. 1). For museum purposes a 20 per cent. solution might be useful, since it leaves a nice surface on the metal; but, as will be seen in the sequel, other, cheaper and more rapid, reagents would probably be more serviceable.

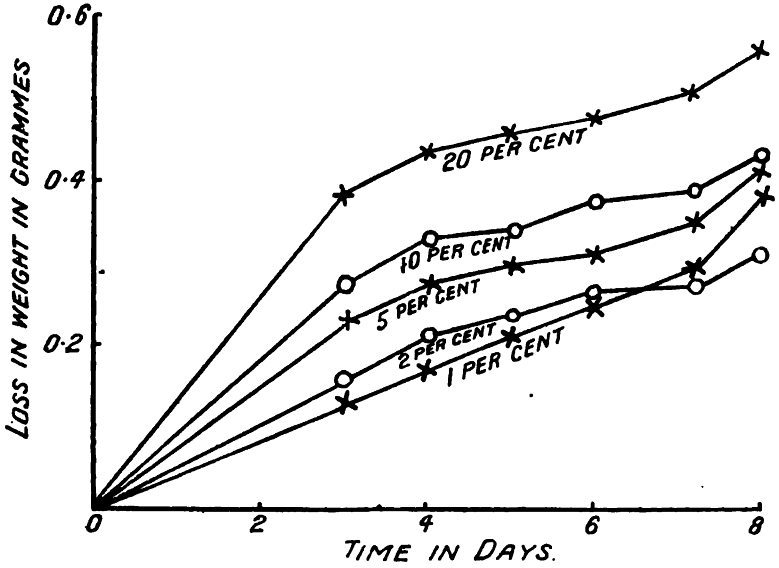

FIG. 1.—Removal of Rust in Sodium Citrate Solution.

Boric Acid.

The concentrations of boric acid employed were 0·5, 1·0, 1·5, 2·0, and 3·5 per cent., the last named being saturated.

The mean weight of rust removed by mechanical means from similar plates of rusty iron was 0·2085 gramme. It will be observed that all the solutions tend to clean the iron, the saturated solution acting the most rapidly. When once the rust has been removed, the iron dissolves very slowly in the solution, so that graphs (Fig. 2) become very flat. Despite the slow rate of solution of the cleaned iron, the loss involved in the removal of the rust is 75 per cent. more than the mean obtained by mechanical methods (0·2085 gramme).

Days.	Loss in Weight of Rusty Plates.				
	1	2	3	4	5
	Gramme.	Gramme.	Gramme.	Gramme.	Gramme.
1	0·0472	0·0990	0·1622	0·1968	0·3260
2	0·1242	0·1044	0·1646	0·1990	0·3566
3	0·1310	0·1968	0·1696	0·2030	0·3602
4	0·1742	0·1984	0·1736	0·2100	0·3620
7	0·3060	0·3400	0·2720	0·2184	0·3690
11	0·3742	0·3857	0·3584	0·3742	0·3878[1]
14	0·4002	0·4181	0·3614[2]	0·3764	0·4054
Boric acid	0·5 per cent.	1·0 per cent.	1·5 per cent.	2·0 per cent.	3·5 per cent.

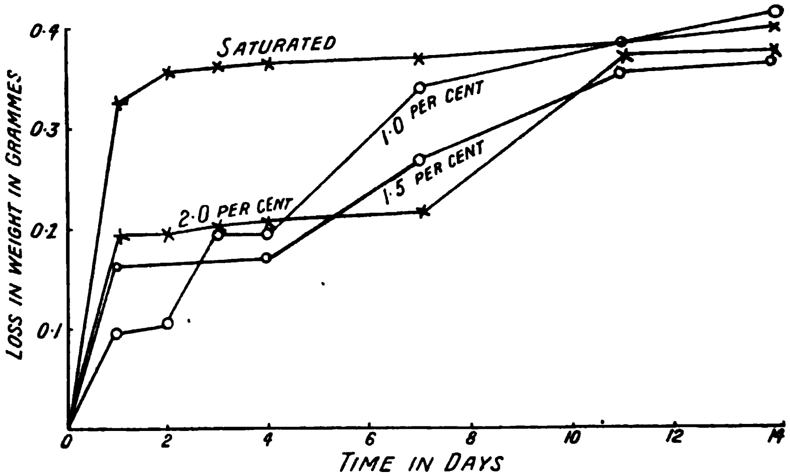

FIG. 2.—Removal of Rust in Boric Acid Solution.

Various other chemical reagents were tried, but none of them proved as useful as boric acid, and it did not appear possible to find a reagent that would remove rust quantitatively without also dissolving some of the iron. Ten per cent. solutions of aluminium sulphate cleansed the iron in twenty-four hours and yielded an excellent metallic surface.

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[1] Began to rust again.

[2] Nearly clean.

A 1 per cent. solution of chromic acid removed rust only excessively slowly, a plate of metal not becoming clean in six weeks, during which period it had lost 0·2448 gramme in weight.

Saturated solutions of zinc sulphate and of magnesium chloride were also tried. In the former the rust turned black in colour, and signs of cleaning were apparent in the latter only after eleven days.

A 10 per cent. solution of ferrous sulphate cleaned a piece of iron in a fortnight, the loss in weight being 0·4588 gramme (by mechanical cleaning, 0·2394 gramme).

An attempt was also made to clean some plates by immersing in 5 per cent. caustic potash solution in contact with granulated (and in some cases powdered) zinc, the surface of the plates being scratched free from rust in places to insure good contact.

The rust was converted into a blackish mass containing a high percentage of ferrous oxide, but no satisfactory cleaning action was observed. A plate of pure Kahlbaum's foil, entirely free from rust, when immersed in caustic potash solution in contact with zinc, slowly gained in weight after the first day.

Since it appeared impossible to find a reagent that would remove rust quantitatively without also dissolving some of the iron, it occurred to the authors that if the plates were immersed in sulphuric acid until the rust had been loosened, the amount of iron passing into solution could easily be estimated by titration of the acid in the usual way with permanganate, and this subtracted from the total loss in weight of the plates would give the loss due to rust. It was found, however, that if the layers of rust were thick the nascent hydrogen liberated during the initial stages of solution of iron reduces some of the more closely adhering rust to the ferrous condition, with the result that the subsequent titration yields too high a value and the apparent weight of rust is too low.

CORRESPONDENCE.

Professor T. TURNER (Birmingham) wrote that he was of opinion that the researches were of both practical and scientific value, but that much further work was required before any definite conclusions could be reached. As the authors pointed out, their conclusions applied only to the particular metals tested, and it might be added also to the particular methods applied in testing. One sample of mild open-hearth steel gave but little idea of the behaviour of the whole range of steels. Similarly one grey cast iron might give very different results from those obtained from another sample. The influence of the percentage of carbon upon the rate of corrodibility of steel had already been brought before the Institute, and doubtless other elements such as silicon, manganese, and nickel would have a marked effect in steel. In cast iron also, composition and structure have great influence. As a general rule it would appear that irons containing large flakes of graphite were more susceptible to corrosion, especially by acids. Ferrite was preferentially attacked by acids, while iron carbide and phosphide remained behind in the carbonaceous residue. It was well known that acid-resisting cast-iron vessels were usually made of very close-grained material. In some cases white iron was preferred, and some addition of phosphorus was recommended. With alkaline liquids the reverse action appeared to take place, as the iron carbide was dissolved, while the ferrite remained unattacked. These facts should be borne in mind in connection with any extended tests of the relative corrodibility of cast iron. Further, it should be remembered that in practice, where iron columns and similar castings were exposed to atmospheric influences, they were always used with the skin on, and that appeared to be of very great advantage.

The authors in reply wrote that they quite appreciated the force of Professor Turner's criticism. Laboratory experiments were very valuable as guides to indicate the kind of results to be expected in actual practice. The Iron and Steel Institute had awarded one of the authors a Carnegie Scholarship, in order that a comprehensive series of field tests might be carried out on a large scale to determine the relative corrodibilities of various forms of commercial iron and steel as manufactured by different British firms. It appeared to be conclusively proved, not merely by the foregoing research, but by numerous other investigations, that no one kind of iron or steel was more resistant to all corrosive influences than another. Each metal apparently exhibited an optimum resistance to certain types of corrosion. It was hoped that, in due course, as the result of the field tests, it might be possible to state what forms of iron and steel were specially suitable for withstanding corrosion under any particular conditions.

STRESS-STRAIN LOOPS FOR STEEL IN THE CYCLIC STATE.

By Professor J. H. SMITH, D.Sc., Wh.Sc.,
AND
G. A. WEDGWOOD, B.Sc., Wh.Sc. (Belfast).

INTRODUCTION.

In a paper read before the Iron and Steel Institute, September 1910, an account was given of a method of arriving at a series of yield ranges for mild steels. Endurance test results recorded in the paper for samples of the same materials led the authors to suspect that the yield ranges are identical with the Wöhler limiting ranges.

The determination of a complete series of Wöhler ranges for any material requires a great amount of time and a large number of specimens, whereas the corresponding yield ranges for any quality of mild steel may be determined from experiments on a single specimen in a very short time. The question of the relation between these ranges has not been dealt with by other experimenters, so far as the authors know, although the point is of some importance in the subject of Strength of Materials.

In the work now about to be recorded, the object has been to examine in detail the character of the stress-strain loops met with in experiments on yield ranges. No further work has been done by the authors on the comparison of the Wöhler ranges with the yield ranges, as it would appear to be better for other experimenters to check the work.

The meaning of "yield range" has been already fully explained in the paper alluded to, but a little further explanation will perhaps not be out of place here.

YIELD POINTS AND YIELD RANGES.

If a material be subjected to direct stress of gradually increasing magnitude the points of interest in the stress-strain curves, so far as this work is concerned, are the limits of proportionality, the elastic limits, and the yield points.

The limit of proportionality is the stress at which the linear relation between stress and strain ceases, as the load is increased from zero. The elastic limit is the greatest stress which may be applied without producing a strain when it is removed. The yield stress corresponds to the state for which the stress-strain curve becomes parallel to the axis of strain. At the yield point, the amount of strain depends to a certain extent on the length of time during which the load acts.

Limits of proportionality, elastic limits, and yield points are observed both in tension and compression. Apparently, in a certain state of a material which may conveniently be looked upon as a normal state—thus distinguishing it from the primitive state—the limits of proportionality in tension and compression correspond to the same stress, as do also the elastic limits and the yield points.

If a material be subjected to alternating stress of high periodicity (about 1000 alternations per minute), and at the same time direct stress (in future called "mean stress") be applied, it is found as a result of experiment:—

(1) That the strain due to the alternating stress does not vary very much, if at all, when any change occurs in the mean stress, unless the material is either about to yield or rupture.

(2) That the mean strain, arising from slow application of mean stress, gives rise to phenomena similar to those observed in ordinary tensile and compression tests—that is, limits of proportionality and yield points are observed.

The ranges corresponding to the yield, when found in this manner, are spoken of as "yield ranges." It may be noted that to specify completely a yield range both the alternating range and the mean stress are required. One of the authors of this paper has already suggested that these yield ranges are identical with the limiting ranges of Wöhler.

When first approaching the work it might be imagined that the maximum stress of the yield range would always be the yield stress of the material, but experiments show that this is not the case. It is found that the maximum stress of the yield range may be greater or less than the ordinary yield stress of the material, according as the range employed is less or greater than the ordinary yield stress, and that the ordinary yield stress of the material corresponds approximately to the yield range when one limit of the range has zero value.

In commencing experiments on a material in the primitive state, as ordinarily supplied by the manufacturer, it is often found that the maximum stress of the yield range is the yield stress of the material, but that after the material has yielded a slight amount, a new state is set up.

In carrying out a series of experiments in which a slight overstrain is allowed, it is only natural to aim at an order of operations by means of which the effects of the previous overstrain, or yield, may be removed. The natural order would be to carry out a yield test in tension, and follow it by a yield test in compression, employing the same alternating stress range in each case. If this were done it would seem that very little damage would be done to the material. Moreover, the question as to whether damage has been done could be investigated in a simple manner by repeating such tests; for if, on repeating, the stress-strain curves occurred under the same conditions, it would be reasonable to assume that the material had not suffered.

Considerations such as these naturally lead to the carrying out of tests in a cyclical order somewhat as follows: The material is subjected to a chosen range of amount known to be safe with zero mean stress. Mean stress is applied in tension, and the strains are noted. The mean stress is now changed very gradually to an equal amount in compression, and the strains are again noted. These operations are repeated a number of times, and it is observed that the extreme strains settle down to definite values, which are repeated with every reversal of mean stress. The operations are now repeated with equal and opposite mean stresses of greater and greater values, and it is found that the extreme strains in each case settle down to fixed limits, until finally, conditions are reached at which yielding occurs at the tension limit, the compression limit, or both limits.

A series of operations of the kind just described enables an operator to obtain a complete set of yield ranges.

If, after determining a yield range by these cyclical operations, the operations are repeated with gradually diminishing and slowly applied mean stress ranges, the material is brought back to a normal state. This normal state is not a primitive state, but a state in which there is an elastic range which is apparently the Bauschinger range.

The operations consist in all cases of cyclical mean stress variations of very low periodicity, impressed on the material when it is simultaneously subjected to an alternating stress range of high periodicity.

The Materials Employed.

In order to obtain results conveniently, with the apparatus at the authors' disposal, a material of low yield stress was essential, and for this reason very mild steels were experimented upon. The authors applied to various steel manufacturers, and their best thanks are due to Messrs. The Lanarkshire Steel Co., Ltd., Motherwell, and Messrs. The Frodingham Steel Co., Ltd., Scunthorpe, for their kindness in supplying bars of low carbon content, together with the chemical analysis of the steels.

The analysis of the steels is shown in the following table:—

Steel supplied by—	Carbon per Cent.	Silicon per Cent.	Sulphur per Cent.	Phosphorus per Cent.	Manganese per Cent.
The Lanarkshire Steel Company . . .	0·11	...	0·045	0·049	0·59
The Frodingham Steel Company . . .	0·10	trace	0·04	0·03	0·45

In the ordinary tensile test, with specimen ¾-inch diameter and extensions measured for an 8-inch length, these steels gave the results shown in the following table, the stresses being in tons per square inch:—

Steel supplied by—	P Point.	Yield Stress.	Maximum Stress.	Breaking Stress.	Elongation per Cent.	Contraction per Cent.
The Lanarkshire Steel Company .	13·6	15·6	24·5	18·1	33·7	65·0
The Frodingham Steel Company .	14·2	14·9	22·3	16·1	32·5	56·2

N.B.—Throughout the work on these two steels, the Lanarkshire steel will be denoted by "W," and the Frodingham steel by "G." The specimens dealt with were numbered W1, W2, W3, and G1, G2, G3, &c.

Description of the Apparatus.

The fatigue-testing machine used throughout this work is described fully in *Engineering*, July 23, 1909, and a rough perspective of the general arrangement is given in the paper previously referred to in the introduction. It is advisable to give a short account of the apparatus as applied in the work recorded below.

A sectional plan of the essential part of the machine, together with an enlarged section of the detail around the specimen, is shown in Fig. 1, Plate XLIX.

The application of mean stress to the specimen is obtained by means of a strong spiral spring, which is inserted so as to place the specimen in either tension or compression as required. The load is varied by means of a hand wheel and screw. A clockwise rotation of the hand wheel compresses the spring, and puts the specimen in tension; a load in compression is obtained by rotating the hand wheel in an anti-clockwise direction.

The spring was carefully calibrated several times during the investigation, and it was found that the change of load corresponding to one turn of the hand wheel was 95·3 lbs. In this paper it is convenient to record changes of load and ranges of stress in terms of "turns on spring," or simply as "turns."

The section of the detail surrounding the specimen shows how the specimen is attached to the frame of the machine and to the end of a spring-loaded spindle. It should be observed that the specimen is prevented from buckling by use of the split-steel bearing, in which the specimen can move freely.

Fig. 1 also shows how changes of length of the specimen are measured. The extensometer is of the Martens type, but instead of the usual telescope and graduated scale, an arc lamp, condenser, small orifice, and a transparent screen are employed. It was found in calibrating the scale on this screen, that a movement of 1 centimetre of the spot of light was equivalent to an average change of 0·0005 inch in length of the specimen. It is estimated that this extensometer measures to $\frac{1}{50000}$ of an inch. It can be understood that, on account of the wear of the double knife-edge, the value of the extensometer screen division in terms of the change in length of the specimen is not always constant.

With the object of reducing the labour involved in this investigation, the extensometer readings were not tabulated, but were plotted at once on specially ruled paper, the movements of the spot of light being plotted as abscissæ, the turns on the spring as ordinates.

On the specially ruled paper referred to, the ordinates were inclined at an angle of 46°. This practice was adopted in order to make the stress-strain loops more compact, and, at the same time, to bring elastic lines approximately perpendicular to the horizontal or strain axis.

When a load is put on the specimen in tension, the change in length of the specimen is shown by a movement of the spot of light towards the left-hand end of the extensometer screen; loads in compression cause the spot of light to move towards the right-hand end of the screen. Alternating stress produces an illuminated line on the screen, and when mean stress is simultaneously applied in addition to the alternating stress, the illuminated line travels to the left or right of the screen, according as the mean stress is tensile or compressive.

It is, perhaps, scarcely necessary to point out that results having a great degree of accuracy, from the point of view of mean stress, are not to be expected from this apparatus. In measuring mean loads on the specimen, for example, the authors only claim to be able to measure stress to within about a quarter of a ton per square inch. A great degree of accuracy, however, is not essential to the value of these results, as they are only interesting from a comparative standpoint.

THE STATIC STRESS-STRAIN LOOPS.

The Cyclic State.

The tests here described were carried out on the specimen W6 (diameter = 0·2486″). Several other specimens were dealt with in this part of the work, but the above specimen gave the most regular results. Previous to the carrying out of these tests, the material of the bar had been brought into a particular state, which is spoken of as "the cyclic state."

This state may be defined thus: A material is in the cyclic state when its yield stresses are equal in tension and compression.

The process to be gone through in order to bring the material into this state by slowly applied stress is simple. but the work is sometimes of a very laborious nature. The yield points must, of course, be approached from the primitive state, and the elastic line be plotted, but it is generally found that a material in the primitive state does not yield under the same load for tension and compression. By repeating the loading operation several times up to the yield points, and allowing slight yields to take place, the value of the yield limits may be equalised, and the material then acquires "the cyclic state."

When the material has been brought into the cyclic state, it is found that the stress-strain diagrams are complete loops, so long as the stresses do not fall outside the equal yield stresses referred to. Moreover, it is found that as the range of loading is generally reduced, the loops diminish in size; and, if the range is kept throughout between equal and opposite limits, the loop becomes a straight line, and the range of stress is then apparently the same as the Bauschinger range. The regularity of the results obtained from specimens, which have been carefully brought into the cyclic state, forms one of the most interesting features of the work. The character of the curves is shown in the results of tests recorded below. Some hundreds of experiments have been carried out on the points here dealt with; the authors have chosen from their collection the stress-strain curves which they consider most interesting.

Results of Static Tests.

The tests recorded below were not carried out in the order in which they are presented. When working between stresses corresponding to the yields, the actual strains, depending as they do on the time during which the stress acts, may be varied greatly.

Hence, stable loops of fixed magnitude cannot be obtained. As the yield is approached the material gradually takes up this unstable condition, and the failure to obtain a loop is a criterion of a yield. The material was first brought into the cyclic state; a symmetrical stress-strain loop of maximum dimensions had been previously generated, and the properties of the material in the cyclic state were investigated in the order shown in the Figs. 7, 8, 10, 9, 14, 2, 3, 4, 5, 12, 13, 11, and 6.

Prior to obtaining the results recorded in Figs. 2, 3, 4, and 5, the material had been brought into the Bauschinger state, had then had a long period of rest, and had therefore partially returned to its primitive state.

The authors' reason for presenting the results of this part of the work in the order given is that by so doing they have given the record a logical sequence. Had time permitted, they might have repeated the above series of experiments on another specimen in the order of Figs. 2 to 14, and they have not the slightest doubt that the results would have been identical. This will be seen when the question of repetition of results is dealt with.

The nature of the loading is best shown in a tabulated form as follows:—

Method of Loading the Specimen.

2 turns on spring in tension to 2 turns compression.
4 ,, ,, ,, 4 ,, ,,
6 ,, ,, ,, 6 ,, ,,
8 ,, ,, ,, 8 ,, ,,
10 ,, ,, ,, 10 ,, ,,
12 ,, ,, ,, 12 ,, ,,
14 ,, ,, ,, 14 ,, ,,
15 ,, ,, ,, 15 ,, ,,
16 ,, ,, ,, 16 ,, ,,

These loads and the corresponding readings of the extensometer plotted in Fig. 2 show the elastic line TE and EC for tension and compression respectively.

It will be observed in the diagram that the elastic lines are parallel, and not continuous. This discrepancy is evidently due to the backlash of the loading screw. Actually, the backlash of the screw amounted to 2 millimetres of the scale reading, and may be neglected in our results, which are of special interest from a comparative standpoint only. It may be stated here that in all plotted results the backlash effect is neglected.

The specimen was further loaded in tension to 17 turns of the spring, and the stress-strain line was found to bend over slightly, as indicated in Fig. 3. On gradually unloading back to zero, and subsequently adding a compression load up to 17 turns, the path 2, Fig. 3, was traced.

Removing the load gradually back to zero, again loading the specimen to 17 turns in tension, the path 3 was traced and the loop shown was obtained. This curve is referred to as "the seventeen loop," since the path is described in plotting extensometer readings corresponding to loads from 17 turns in tension to 17 in compression.

One more turn in tension was then added, and, proceeding as in the experiment already described, "the eighteen loop," and afterwards "the nineteen loop," were traced. These loops are shown in Figs. 4 and 5. The arrows in all cases show the direction in which the loop was generated.

It was considered inadvisable to experiment above "the nineteen loop," as a definite yield of the material might be expected with higher stresses.

All the investigations in this section of the work then were concentrated in the range represented by this loop.

The Properties of the Static Stress-strain Loop.

It was observed that the shape of these loop curves was remarkably symmetrical, and that the curves were made up of two straight portions, always parallel to the elastic line, and two curved portions.

The authors found that any one of these loops might be traced over and over again, and that the only change which occurred was an improvement in the shape of the loop with respect to symmetry. For this reason they always made it a practice, before tracing the nineteen loop, to subject the specimen several times to the cycle of operations necessary to the generation of the loop.

They also observed that the original elastic line, Fig. 2, lay approximately in the centre of the nineteen loop. In fact, all the loops appeared to be symmetrical with respect to this elastic line.

Effect of Period of Rest on Static Loops.

The effect of various periods of rest on the material previously brought into the condition represented by the nineteen loop was investigated.

It was found that a rest of twenty-four hours had no great effect on the size or shape of the loop. The experiment was carried out as follows:—The nineteen loop was traced at the beginning of the twenty-four hours, the material was allowed to rest in the condition represented by the point A, Fig. 5. At the end of the twenty-four hours, in bringing the material through the nineteen loop cycle of operations, the four points, A, E, F, K, were observed on the scale to have remained stationary. Finally the loop was traced, and it was found not to have altered in shape.

A similar experiment with the object of investigating the effect of a rest of fourteen days was tried on the same specimen initially in the condition represented by the point F, Fig. 5.

The efforts to obtain the original nineteen loop are represented in Fig. 6, and in this figure the original nineteen loop is shown in dotted lines. It will be seen that the authors obtained a series of loops of varying shape.

As they subjected the specimen to the usual treatment, the loops traced became wider and wider, until finally the original loop was almost obtained. The authors are convinced that had they continued their work long enough, the material would eventually have been brought into the condition represented by the original loop. It will be observed that the material had been changing during its period of rest in the direction of its primitive state.

In the remaining experiments here recorded, the nineteen loop was traced and retraced throughout the work. The reason for doing this is obvious, when it is remembered that the condition of the material is not altogether stable, under the action of a load of nineteen turns on spring, either in tension or compression.

Sometimes it was found that the loop shifted its position on plotting, while other times it appeared to remain in the one position for quite a long time.

The curves shown in Fig. 7 were traced as follows:—

Starting at the point A of the loop, the specimen was loaded in tension up to the point B, which corresponds to a load of thirteen turns on the spring. It was then gradually unloaded back to zero, and again gradually loaded in tension up to seventeen turns on the spring. The strains observed on plotting led to the result shown in the Fig. referred to. These operations were repeated for the points C and D, and curves of a similar character to that of the point B were traced. Finally, reaching the nineteen turn limit, it was found that the point E was not quite at its original position. This, of course, is what might be expected.

The nineteen loop was generated before proceeding with the next series of experiments.

Experiments similar to the above were carried out employing compressive instead of tensile stress, and similar results were obtained. The record of these is given in Fig. 8.

The next series of experiments, represented by Figs. 9, 10, 11, and 12, were carried out with the object of investigating the character of unsymmetrical loops. Having generated the nineteen loop, the authors commenced at the point A, Fig. 9, and loaded the specimen in tension up to ten turns on the spring—that is, to the point B on the loop. The load was then reduced to zero, and a compression load was added up to the nineteenth turn limit. During these operations the stress-strain curve A B B′ K was plotted, the character of which is obvious from an inspection of the diagram (Plate L.).

The unsymmetrical loops for the point C, fifteen turns, and for the point D, eighteen turns, were also obtained in a similar manner. It is interesting to note how smoothly these fall in with the shape of the circumscribing loop.

Starting at the point F, and confining their attention to limits on the compression side of the nineteen loop, the authors traced the unsymmetrical loops for the points G, H, J, and L, corresponding to 10, 15, 17, and 18 turns respectively, as represented in Fig. 10. A glance at the figure is sufficient to show the similarity of these results to those already described when the variable limits were on the tension side.

It is no longer necessary to go into details in describing the tracing of the unsymmetrical loop D D′ D″ in Fig. 11, where the upper limit was fixed, and the unsymmetrical loops G G′ G″, H H′ H″, and J J′ J″ in Fig. 12, where the lower limits were fixed.

Confining their attention to any one of these unsymmetrical loops, *e.g.* D D′ D″, Fig. 11, the authors found that the loops traced with gradually diminishing ranges but of fixed upper limits became smaller and smaller, until finally the smallest loop they were able to trace was practically an elastic line. It may be observed that this elastic line, for the material became elastic, is not in the centre of the unsymmetrical loop. It is also interesting to note that the four elastic lines thus obtained had an elastic range of about nineteen turns on the spring, suggesting that elastic ranges arrived at in this manner having one limit on a given loop are of equal magnitude.

It was found that the path traced when the material was loaded after being brought into one of these elastic conditions, was as shown in Figs. 11 and 12. The stress-strain lines gradually merged from the elastic lines into points on the original nineteen loop curve, and show limits of proportionality and yield points as indicated by D *d* E in Fig. 11 and by G *g* H, H *h* J, and J *j* K in Fig. 12.

These results suggest that the nineteen loop is the locus of a series of "yield points" arrived at when passing from the various elastic ranges obtained from the nineteen loop state in the manner indicated.

Special attention was paid to the straight portion EF of the extreme loop (see Fig. 13). Having generated the nineteen loop several times, and arrived at the point F, the authors loaded again in tension to the nineteen limit. They found that the path traced was not a repetition of the approximately straight path EF. On further repeating these operations of loading and unloading between zero and nineteen tension turns, they were unable to obtain a final loop line from which any deduction of interest could be made. This might have been expected, since the material was in a rather unstable condition at this part of the loop, and the elastic range was approximately constant, and equal to the range with which they were experimenting.

Before commencing another series of experiments on the same specimen, the material was brought into the condition represented by the + 11 turns to − 11 turns line, and in doing this, the eighteen, seventeen, sixteen, fifteen, fourteen, and thirteen loops were traced, and are shown in Fig. 14.

The authors have found it convenient to allocate some name for that state of a material in which the elastic limits, obtained after a yield, correspond to equal and opposite stresses. When a material has been previously brought into the cyclic state these elastic limits are apparently always equal in tension and compression. The name adopted throughout this paper for this particular state, as represented by the elastic line + 11 turns to − 11 turns arrived at from the greatest possible symmetrical loop in the manner indicated in Fig. 14, is the Bauschinger state.

Examining the curves of Fig. 14, it was observed that in generating the loop as shown in Figs. 2 and 3, the material maintained its elasticity for a load as great as sixteen turns on the spring in tension and in compression, instead of giving the thirteen, fourteen, fifteen, and sixteen loops. When a specimen of a material, in the cyclic state, is left to rest in the machine, the elastic range always increases in value, and the material gradually returns to the primitive state, but after one of the elastic limits is passed the material falls into the cyclic state quite readily.

The preliminary experiment which was carried out on specimen W6 before it acquired the cyclic state is not placed on record, as it was a very tedious one. The material, prior to the plotting of the nineteen loop, was subjected to the cycle of operations of this many times before a symmetrical loop was obtained.

It must not be inferred, however, that a troublesome operation is always necessary before the cyclic state is secured, for the authors have actually obtained the nineteen loop for specimens of the "W" by simply performing a few +19 and −19 cycles of stress variations.

In general, however, the cyclic state is most easily arrived at by applying an alternating stress range of high periodicity. Large ranges, however, cannot then be employed, as rupture would occur. Hence the means adopted, as will be seen presently, consist of employing a small alternating range of high periodicity together with a slowly varying mean stress.

STRESS-STRAIN LOOPS FOR STEEL IN THE CYCLIC STATE SUBJECTED TO MEAN STRESS AND A SUPERIMPOSED ALTERNATING STRESS RANGE OF CONSTANT PERIODICITY.

The Apparatus Employed.

The apparatus employed has already been described. The mean stress on the specimen is varied by means of the spring, and its value is recorded in the various curves and tables either in tons per square inch or spring turns. The alternating stress range is obtained by means of revolving masses attached to cranks of radius of 5 inches. These cranks are not shown in Fig. 1, but their position is indicated.

The periodicity of the alternating stress is obtained by means of a tachometer, driven by the machine, which records the speed of the machine with a degree of accuracy approximately 1 per cent.

The greatest errors which may occur in stress determination are ¼ ton per square inch in mean stress and a 2 per cent. error in alternating stress ranges. Greater accuracy can be obtained if more time is expended in experimenting.

The strains arising from the alternating stress range are measured by means of a ray of light reflected from a concave mirror mounted on a double knife-edge. In these experiments an illuminated line is used, and not a spot of light. In order to specify completely the strains, the length of the illuminated line and the change of position of its mid-point are noted. The length of the line naturally varies with the change of speed of the machine. In all the tests recorded below an effort was made to maintain a constant speed, but in some cases variations of 1 per cent. were noted.

The results were plotted in the same manner as that already described in Part I., axes inclined at 46° being employed. The diagrams which follow show the position of the mid-point of the illuminated line as the oblique ordinate.

Properties of the Stress-strain Loops when Mean Stress and a Superimposed Alternating Stress Range of Constant Periodicity are Employed.

The tests are of a similar character to those already described. The loops shown in Figs. 15 and 16 were traced for the specimen G6 (diameter, 0·249 inch). Throughout the tracing of these loops the alternating stress was 15·3 tons per square inch at a periodicity of 940 alternations per minute. The loading of the specimen in tension and compression with mean stress was as follows:—

2 turns on spring in tension to 2 in compression.
4 ,, ,, ,, 4 ,,
5 ,, ,, ,, 5 ,,
6 ,, ,, ,, 6 ,,
7 ,, ,, ,, 7 ,,

The readings of the mid-point of the illuminated line are shown plotted in Fig. 15 (*a*), but maximum strains corresponding to the above five changes of loading are alone plotted. It is seen in Fig. 15 (*a*) that the stress-strain line bends over slightly for mean stresses greater than about two turns. A distinct elastic limit is observed to have been reached at 1·6 ton per square inch in tension and compression. Thus, for mean stress variations with the limits $+2$ and -2 turns the material is elastic; for greater variations of mean stress the material is no longer elastic, and the stress-strain curves are loops. In Fig. 15 (*a*) the extremities of the loops only are plotted.

By varying the mean load through a cycle of 16 turns, 8 turns in tension and 8 turns in compression, the closed path shown in Fig. 15 (*b*) was traced. This closed curve is spoken of as "the eight loop."

Half a turn was added in tension, thus leading the specimen up to 8½ turns, and "the eight-and-a-half loop" was traced in the same manner as "the eight loop." "The nine loop" was also traced. These loops are shown in Figs. 15 (*c*) and 15 (*d*), the arrows in all cases showing the order in which the tests were carried out.

The specimen was next loaded up to 9½ turns in tension and "the nine-and-a-half loop" traced as shown in Fig. 16 (*a*). Previous experience shows that a definite yield would have taken place had any more mean stress been added, and for this reason it was deemed advisable not to increase the load on the specimen any further.

A yield, as considered here, is detected by the breaking away of the stress-strain curves from the loop or cyclic state.

The nine loop was again traced, and the material was brought back into the Bauschinger state by unloading as follows:—

9 turns in tension to 9 in compression.
8 ,, ,, 8 ,,
7 ,, ,, 7 ,,
6 ,, ,, 6 ,,
5 ,, ,, 5 ,,
4 ,, ,, 4 ,,
3 ,, ,, 3 ,,
1 ,, ,, 1 ,,

In Fig. 16 (*b*) the intermediate loops for the limits 8, 7, 6, 5, 4, and 3 were not plotted in detail, but the locus of extremities of the loops was plotted, and it may be observed that the Bauschinger state was again arrived at, as represented by the elastic line between limits + 1·6 and − 1·6 tons per square inch in Fig. 16 (*b*).

The Properties of the Mean Stress-strain Loops.

Experiments were carried out with the object of comparing the mean stress-strain loops with the static loops previously dealt with, and Figs. 17 and 18 show the results of these experiments. (See Plate LI.).

The specimen W6, which had been tested statically, as described on pp. 371–378, was subjected to an alternating stress range of 6·9 tons per square inch—that is 8 turns—of periodicity 485 alternations per minute, and "the fifteen loop" was generated. Special care was exercised in tracing the loop, a definite period of fifteen minutes being spent in carrying out the cycle of operations.

The material of the specimen was then brought into the condition represented by the point A in Fig. 17, and the alternating stress range was removed by stopping the machine.

Starting at the point A in Fig. 17 the authors traced "the nineteen static loop," and the rate at which readings were taken was so arranged that the cycle of operations again took exactly fifteen minutes.

The curves for these two experiments, plotted with the same axes, are shown in Fig. 17, and their similarity can be seen. The width of these loops is practically the same. By adding half the alternating stress range, *i.e.* 4 turns, at various points of "the fifteen loop," a loop of almost the same dimensions as "the nineteen static loop" may be obtained. The authors are therefore of opinion that the static loops, and the loops obtained under alternating ranges of variable mean stress, are almost identical for the special case in which the mean stress varies between equal and opposite values.

The test represented in Fig. 18 was a repetition of the previous one, and was carried out on specimen W11. The remarkable similarity between "the twelve loop" and "the sixteen static loop" is again seen in the figure. The slight discrepancies in both these and the last experiments occur, it may be noted, at the points of maximum stress.

Figs. 19 (*a*) and 19 (*b*) were plotted to demonstrate still further the similarity between the mean stress-strain and the corresponding static loops. The tests were carried out on specimen W11. A constant alternating stress range of 7·5 tons per square inch of periodicity, 492 alternations per minute, was employed throughout. "The twelve loop" was generated commencing with the material in the Bauschinger state, the material was then brought into the condition represented by the point A, and the curves shown in Fig. 19 (*b*) were traced as a result of the operations described below.

The specimen was gradually loaded in tension up to B, 7 turns on the spring, it was then gradually unloaded, and again loaded to 10 turns. The operations were repeated for the points C and D, with results shown in the figure. Exactly similar operations were carried out in compression, and results of a like character were obtained and are shown in the same figure.

Comparing these results with those obtained statically and recorded in Figs. 7 and 8, it was observed that instead of obtaining small loops inside the main loop, straight lines were, with two exceptions, obtained, suggesting definite elastic ranges, leading to the belief that the superimposed alternating stress ranges have the effect of changing the character of the material in a manner similar to the operations shown in Figs. 11 and 12.

It is found that, where care is exercised in maintaining the constancy of range, the stress-strain loops are far more satisfactory from every point of view than the static loops. That the straight portions of these loops are elastic lines follows at once from the results obtained and the method of loading employed, and lead the authors to believe that the illuminated line represents an elastic condition of the specimen under the alternating stress range. In fact, they have been gradually led to the conclusion that, except for the particular case of equal and opposite limits, the alternating range is always an elastic range if no mean strain occurs and the material is not about to rupture.

The unsymmetrical loops of Fig. 19 (*a*) were plotted immediately after the results of Fig. 19 (*b*) were obtained. They are of a similar nature to the corresponding static loops of Figs. 9 and 10, and it is therefore unnecessary to give a detailed account of their plotting. No further examination of the properties of the loops with alternating stress was made, as it was considered that the evidence embodied in the above results was quite sufficient to establish the similarity, and the difference between the mean stress-strain loops for steel subjected to an alternating stress range of constant value, and those loops for the same specimen of steel tested statically.

COMPLETE YIELD RANGE TEST.

The results recorded in the following pages relate chiefly to the stress-strain curves met with in experiments which have for their object the determination of yield ranges.

A specimen, one quarter of an inch in diameter, and 4 inches long, was fixed in the reversal testing-machine, and was subjected to mean stress and alternating stress of periodicity, 800 to 1000 repetitions per minute, the alternating stress range being chosen less than the greatest Wöhler limiting range.

With a given alternating stress range and simultaneously applied mean stress, it has already been seen that the mean strain is proportional to the mean stress up to a certain point, just as in the ordinary static tests. The mean stress-strain line then bends over slightly, until finally the line becomes horizontal. That is, there is a distinct yield point. It is found that with the same alternating stress range under the yielding condition the value of the mean stress in tension is generally the same as the value of the mean stress in compression. The yields are approached by means of a series of loop tests of gradually increasing mean-stress range, and the final failure of the material to give a stress-strain loop is used as the criterion of yield.

When the mean stress on the specimen is zero, the conditions are somewhat difficult to deal with, and the yield range for zero mean stress is seldom determined. Values approaching to it can, however, be obtained in the manner recorded below.

A complete series of yield range results can be obtained from experiments on one specimen, when care is exercised in keeping down the actual yield of the material to small amounts.

The particulars of the first few tests are purposely described very fully, and when the character of the work is understood the figures are sufficient to explain the various operations. As previously mentioned, the mean-stress loading of the specimen in tension or compression is spoken of in terms of "turns on the spring," or more simply as "turns." In all diagrams the loading is referred to as "turns on spring."

The curves of results recorded in this part of the work were obtained for the "G" steel. The two specimens dealt with are denoted by G1 and G3 respectively. The specimen G1 was broken before a complete set of yield range curves was obtained, but these curves are shown, because special care had been taken in tracing them. A complete set of curves was obtained for the specimen G3 without in any way damaging the material, and these are recorded below.

RESULTS OF YIELD TESTS.

TEST 1. SPECIMEN G1. FIG. 20. (PLATE LII.)

Conditions of Test.—The alternating stress range was 7·7 tons per square inch, and the periodicity 930 alternations per minute. The mean stress was varied in a cyclic manner. The material was initially in the primitive state.

The variation of mean stress is represented below, as are also the remarks on the character of the curves.

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves (Fig. 20).
2 turns in tension to 2 compression . .	The plotted strains all fall on the elastic line (1).
4 ,, ,, 4 ,, . .	
6 ,, ,, 6 ,, . .	
8 ,, ,, 8 ,, . .	
10 ,, ,, 10 ,, . .	
12 ,, ,, 12 ,, . .	
13 ,, ,, 13 ,, . .	
14 ,, ,, 14 ,, . .	
15 ,, ,, 16 ,, . . .	A yield in compression.

The compression yield at 16 turns amounted to approximately three divisions on the extensometer scale.

The mean stress was then reduced to zero, and was increased in tension up to 15 turns on spring, when a yield in tension occurred. This operation is represented by the line (2) of Fig. 20.

The mean-stress load was again reduced to zero, and then increased in compression up to 14 turns, when the specimen yielded. This operation is represented by line (3).

The material was again loaded in tension, and another yield under a load of 14 turns on the spring was observed, the yield being approached by the path shown by line (4).

It will be observed that the material had now been brought into such a state that it yielded in tension and in compression under equal values of mean stress—that is, for an alternating stress of 7·7 tons per square inch, the material yielded under a mean stress of 14 turns on spring (12·2 tons per square inch) both in tension and compression.

It may be noted that the object of these operations was the securing of a state giving similar results on the tension and compression sides. This state the authors have named "the cyclic state."

After this last yield in tension had taken place, the spring was manipulated to give the plotted paths (5), (6), and (7). The path (7) forms a closed loop for 13 turns in tension and 13 turns compression.

The material now being in the cyclic state, it was brought back to the Bauschinger state by unloading in tension and compression as represented below:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves (Fig. 20).
13 turns in compression to 13 tension	The loop was traced.
12 ,, ,, 12 ,,	
11 ,, ,, 11 ,,	
10 ,, ,, 10 ,,	
9 ,, ,, 9 ,,	The elastic line was traced. The Bauschinger state.
8 ,, ,, 8 ,,	
6 ,, ,, 6 ,,	
4 ,, ,, 4 ,,	
2 ,, ,, 2 ,,	

It may be observed that the elastic line, which corresponds with the Bauschinger state thus traced, intersects the horizontal axis 2·6 extensometer scale divisions on the compression side of the scale. Hence the specimen had been shortened.

TEST 2. SPECIMEN G1. FIG. 21. (PLATE LII.)

Conditions of Test.—The alternating stress range was 10·9 tons per square inch, and the periodicity 910 alternations per minute. The mean stress was varied in a cyclic manner.

This test was carried out directly after Test 1, and thus at the commencement the material was in the Bauschinger state.

In approaching the yield range, corresponding to an alternating range of 10·9 tons per square inch, the variation of mean stress employed was as follows:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves (Fig. 21).
2 turns in tension to 2 compression	The elastic line was traced.
4 ,, ,, 4 ,,	
6 ,, ,, 6 ,,	
7 ,, ,, 7 ,,	
8 ,, ,, 9 ,,	
9 ,, compression to 9 tension	The loop was traced for each of these limits.
10 ,, ,, 10 ,,	
11 ,, ,, 11 ,,	
11½ ,, ,, 11½ ,,	
12 ,, ,, 12 ,,	A yield occurred at these limits, and hence it was impossible to obtain a complete loop form.

The mean stress at which a yield occurred was 12 turns (10·4 tons per square inch), both in tension and compression. It may be observed that, owing to the yield strains being unequal, the loop became slightly unsymmetrical with respect to the Bauschinger line.

It is almost impossible to obtain a closed loop for the extreme limits at which the yields occur; loops can be obtained, and can be made of almost any size, being closed by stopping the yield at the desired strain; these, of course, are not real stress-strain loops.

The material was brought back into the Bauschinger state by unloading the specimen in the following manner:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves (Fig. 21).
12 turns tension to 11 compression 11 turns compression to 11 tension	The loop was traced.
10 ,, ,, 10 ,,	
9 ,, ,, 9 ,,	
8 ,, ,, 8 ,,	
7 ,, ,, 7 ,,	
6 ,, ,, 6 ,,	The elastic line was plotted. The Bauschinger state.
3 ,, ,, 3 ,,	
2 ,, ,, 2 ,,	

It should be noted that the elastic line, traced after the yield, intersected the horizontal axis at 2·9 scale divisions on the compression side of the scale. This was due to the slightly unequal yields allowed in tension and compression, causing the line to move in the direction of the greater or compression yield.

In each test which was carried out on this specimen, and also in those carried out on the specimen G3, described fully later, the stress-strain curves obtained in "approaching the yield" and those obtained "after the yield" are shown separately in each figure. This practice was adopted for the sake of convenience.

TESTS 3, 4, 5, 6. SPECIMEN G1. FIGS. 22, 23, 24, 25. (PLATES LIII., LIV.)

The subsequent tests were carried out in a manner similar to that already described in the preceding tests. The treatment of the specimen from the Bauschinger state to the yield, and from the yield back again to the Bauschinger state, was in each case systematic. It is therefore unnecessary to record the treatment of the steel during each test in detail. The tests were carried out in the order represented by the numbers on the various figures. The yield in any particular test was approached from the Bauschinger state acquired after the yield of the preceding test. The relative position of the elastic lines can be seen at a glance by a comparison of the diagrams, remembering that the zero of each diagram is the point at which the original elastic line for the material in the primitive state intersected the horizontal axis, as may be seen in Fig. 20.

In each test, except Test 6, after a yield had taken place a loop approximating to the maximum possible under the conditions of the test was traced in order that one might compare its dimensions before and after the yield.

The intermediate loops were not traced in the subsequent treatment of the material back to the Bauschinger state.

In some cases, it will be observed, the loop traced after a yield was larger than it was before the yield had taken place. This peculiarity may have been due either to a rise in the speed of the machine or to the effects of the actual yielding on the internal structure of the material.

TEST 6. SPECIMEN G1. FIG. 25. (PLATE LIV.)

With reference to Test 6, Fig. 25, of which the alternating stress range was 19·8 tons per square inch of periodicity, 900 alternations per minute, a loop was traced for the limits 4 turns in tension and compression. A mean stress to 4½ turns in tension produced a large and sudden yield of the material. This mean stress was quickly removed, and the material was loaded up to 5 turns in compression. This load was removed, and in adding 3 turns in tension the specimen broke.

The material appeared to have been damaged during the yield in tension. The length of the illuminated line greatly increased during the yield, and it never assumed its original length, which had remained practically constant during the tracing of the loop for the 4 turn limits. It will be observed that the straight line plotted in the process of the unloading from the 4½ turns tension to zero is of much greater slope than any other lines obtained in a like operation. This was generally found to be a sure sign that rupture was about to take place; the illuminated line naturally increased in length under such conditions.

The results of these six tests are tabulated in Table I. The decreasing maximum yield stress for the increasing alternating stress is to be seen in this tabulation:—

TABLE I.—*Results of Experiments on Yield Ranges for Specimen G1.*

The stresses are recorded in tons per square inch.

Test.	Periodicity.	Yield Range Stress.	Turns on Spring.	Mean Stress.	Maximum Stress.	Minimum Stress.
1	930	7·7	14	12·2	16·1	8·4
2	910	10·9	12	10·4	15·9	5·0
3	910	14·3	10	8·7	15·9	1·6
4	920	16·3	8½	7·4	15·6	−0·8
5	910	18·2	6½	5·6	14·7	−3·5
6	900	19·8	4½	3·9	13·8	−6·0

If the values given in the last three columns are plotted as in Fig. 31 (a diagram relating to results obtained from specimen G3), a striking agreement between the results and those of G3 will be found.

In the determination of a series of yield ranges for a material, it was found that slightly more regular results were obtained when the experiments were first carried out with a small alternating range, and then with ranges of greater and greater value in the subsequent experiments.

It is not intended to enter into the question of what happens when any one of these ranges is allowed to produce rupture, as the authors are gradually collecting information on the point; but it may be stated that the yield for small ranges is some hundreds of times greater than any yield allowed in these experiments. When, however, the alternating range is large, that is when the mean stress of the range approaches zero value, the yield, before rupture, is small. For this reason the large yield ranges are more difficult to deal with in groups of experiments of the type recorded above.

Results of Tests on Specimen G3.

The tests carried out on specimen G3 were of a similar character to those of specimen G1. The alternating stress range was gradually increased by succeeding amounts until the yield range for zero mean stress was approximated to.

After this series of tests the first test of the series was repeated in order to discover if any damage had been done to the material. The specimen was then removed from the machine, and put aside for a period of eight months, after which the effect of the period of rest was investigated.

With a few exceptions the yield was approached in the usual systematic manner. No difficulty should be experienced in interpreting the stress-strain curves of this series.

TEST 1. SPECIMEN G3. FIG. 26. (PLATE LIV.)

Conditions of Test.—The alternating stress was 7·4 tons per square inch of periodicity, 900 alternations per minute. The mean stress was, as usual, varied in a cyclic manner, and the elastic line was traced.

The first yield occurred under a mean stress of fifteen turns in compression, and, on reducing the load by one turn, the yield continued, the specimen was then loaded to fourteen turns in tension. No yield occurred, but a yield took place at fifteen turns. The operation of loading the material with mean stress up to fourteen turns in compression and in tension was repeated three times, when it was observed that the yield which occurred at both limits was approximately the same for tension and compression. The loop for thirteen turns tension and compression was then traced, and afterwards the material was brought into the Bauschinger state. The extremities of the various loops occurring in these operations are shown plotted in the figure. The specimen was then 6·4 extensometer divisions shorter than it was when first inserted in the machine.

TESTS 2, 3, 4, AND 5. SPECIMEN G3. FIGS. 27, 28, 29 (*a*), AND 29 (*b*). (PLATES LIV., LV.)

It is not necessary to describe in detail the character of the variation of mean stress for Tests 2, 3, 4, and 5. These tests with a few exceptions were carried out in the usual systematic manner. In each figure it will be seen that two diagrams are plotted. The one on the left shows the stress-strain curves obtained in approaching the yielding conditions.

The one on the right shows a loop of slightly less mean stress range than corresponds to these yielding conditions, as well as the extremities of all the other loops arising during the operations employed in bringing the material into the Bauschinger state. The Bauschinger ranges are clearly marked on all the diagrams of Figs. 27, 28, and 29.

The tests in which the larger alternating stress ranges were employed are a little more interesting.

TEST 6. SPECIMEN G3. FIG. 30 (*a*). (PLATE LV.)

Conditions of Test.—The alternating stress range was 21·6 tons per square inch of periodicity, 930 alternations per minute. The mean stress was varied in the cyclic manner. This test was carried out directly after Test 5.

The variation of mean stress employed is represented as follows:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves [Fig. 30 (*a*)].
½ turn compression to ½ turn tension . . .	The elastic line was traced.
1 ,, ,, 1 ,, ...	
1½ turns ,, 1½ turns ,, ...	
2 ,, ,, 2 ,, ,, ...	The loop was traced.
2½ ,, ,, 2½ ,, ,, ...	,, ,,
3 ,, ,, 3 ,, ,, ...	,, ,,
3½ ,, ,, 3½ ,, ,, ...	A yield occurred at these limits.

The yield occurred when the mean stress was 3½ turns on spring or 3·1 tons per square inch.

The loop for the limits three turns tension and compression was again traced, and the material was brought back to the Bauschinger state.

TEST 7. SPECIMEN G3. FIG. 30 (*b*). (PLATE LV.)

Conditions of Test.—The alternating stress range was 22·8 tons per square inch of periodicity, 955 alternations per minute. The mean stress variation employed is represented as follows:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves [Fig. 30 (*b*)].
½ turn compression to ½ turn tension . . .	The elastic line was traced.
1 ,, ,, 1 ,, ...	
1½ turns ,, 1½ turns ,, ...	The loop was traced.
2 ,, ,, 2 ,, ,, ...	,, ,,

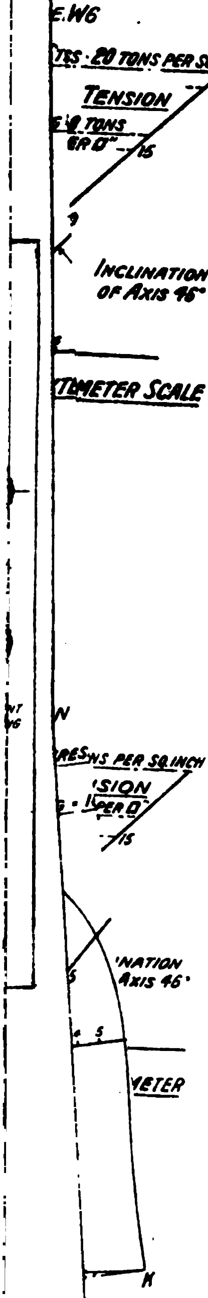
The plotting was at first erratic until the loop for the limits 1½ turns was traced.

The loop for the limits two turns tension and compression was perfectly stable in position. It was observed from the shape of the loop for these limits of mean stress, that a yield would have probably occurred at the limits 2¼ turns (2 tons per square inch). It was therefore decided not to load the specimen any further with mean stress. The material was then brought back into the Bauschinger state, as represented by the line intersecting the horizontal axis 8·3 scale divisions from zero.

Test 8.—The speed of the machine was finally increased up to about 980 revolutions per minute, the alternating stress was then about 24·0 tons per square inch, but no mean stress was applied to the specimen. The position of the line on the screen was observed for about five minutes; no apparent movement was detected.

Not caring to take any risks, larger ranges were not employed, as it was desired to keep this specimen for other work. The yield ranges found in these various tests are given in Table II., and the results are exhibited in a graphical form in Fig. 31 (Plate LVI.). From the graph, Fig. 31, the value of the yield range for zero mean stress is seen to be 24 tons per square inch.

It is perhaps worth placing on record the values of the ranges, corresponding to the Bauschinger states, arrived at in these yield tests. In doing this the authors wish to point out that no particular pains were taken to determine them with accuracy during the tests, and that the results which are given were deduced from the curves as an after-thought. Had the authors wished to obtain more exact values, they could easily have done so by expending a little more time in


E.W6
TES: 20 TONS PER SQ.INCH
TENSION
6·6 TONS
ER □"
15
9
K
INCLINATION
OF AXIS 46°
5
TMETER SCALE
N
RES NS PER SQ.INCH
SION
G - 1 PER □"
15
NATION
AXIS 46°
5
4 5
METER
K

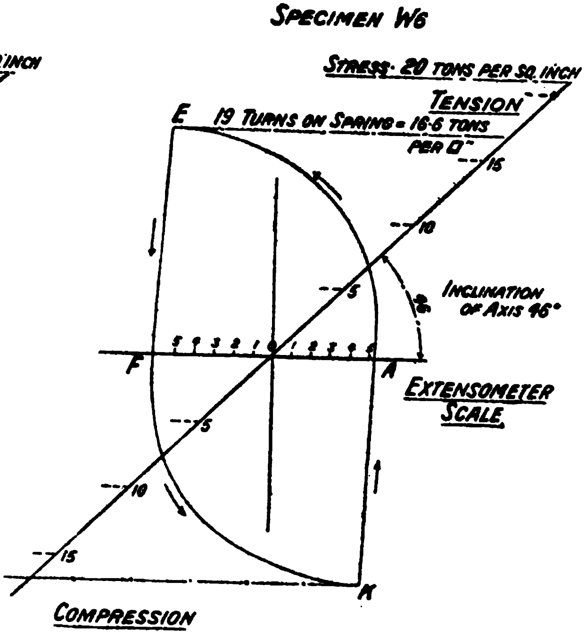

SPECIMEN W6
STRESS: 20 TONS PER SQ. INCH
TENSION
E
19 TURNS ON SPRING = 16·6 TONS PER □"
15
10
5
INCLINATION OF AXIS 46°
46°
5 4 3 2 1 0 1 2 3 4 5
F
A
EXTENSOMETER SCALE
5
10
15
K
COMPRESSION

FIG. 5.

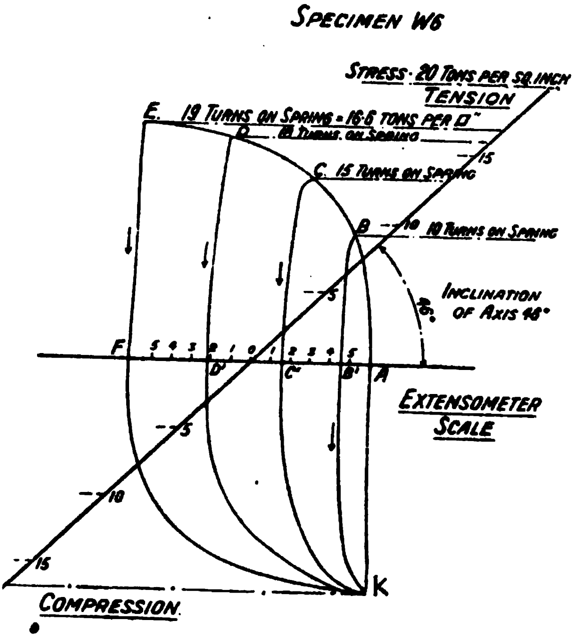

SPECIMEN W6
STRESS: 20 TONS PER SQ. INCH
TENSION
E
19 TURNS ON SPRING = 16·6 TONS PER □"
D
18 TURNS ON SPRING
15
C 15 TURNS ON SPRING
B
10
10 TURNS ON SPRING
5
INCLINATION OF AXIS 46°
46°
F
5 4 3 2 1 0 1 2 3 4 5
D'
C'
B'
A
EXTENSOMETER SCALE
5
10
15
K
COMPRESSION

FIG. 9.

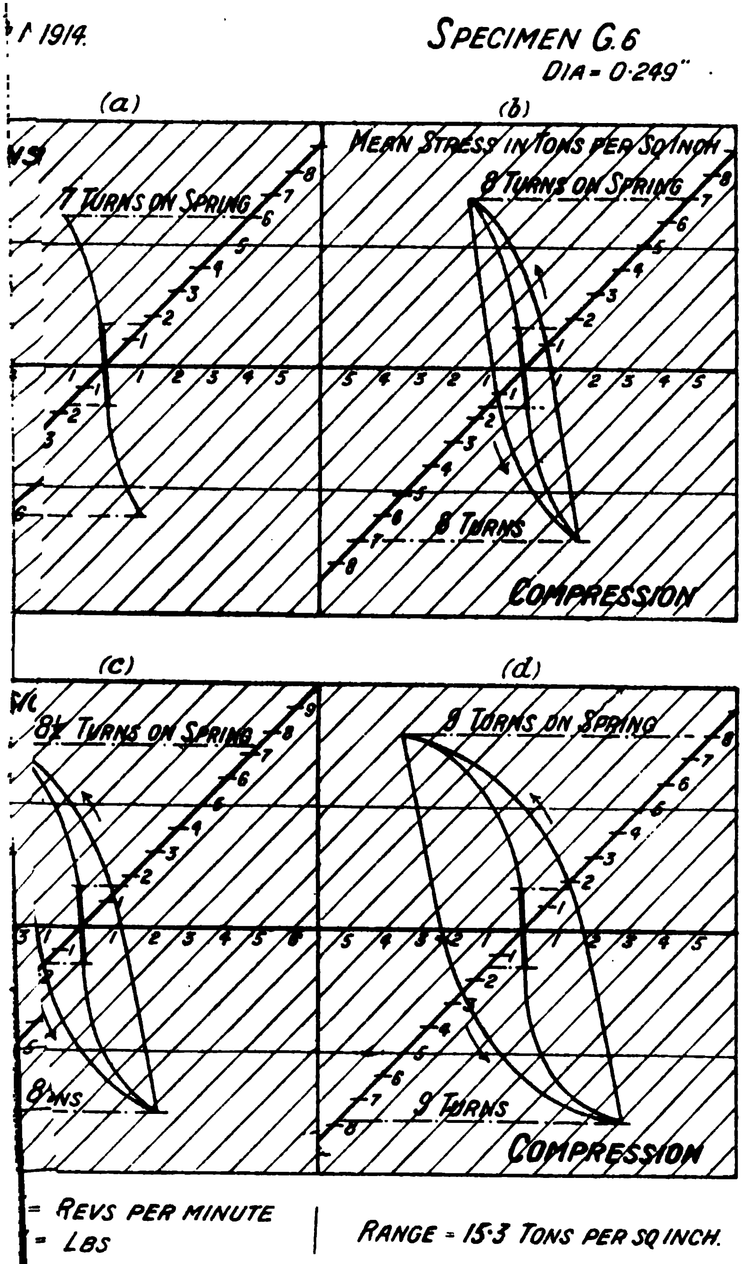
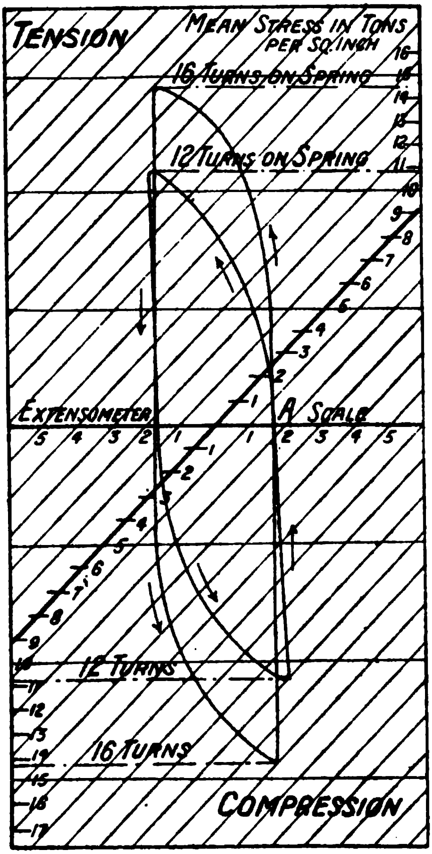

1914.
SPECIMEN G.6
DIA = 0·249"
(a)
(b)
7 TURNS ON SPRING
MEAN STRESS IN TONS PER SQ INCH
8 TURNS ON SPRING
8 TURNS
COMPRESSION
(c)
(d)
8½ TURNS ON SPRING
9 TURNS ON SPRING
9 TURNS
COMPRESSION
= REVS PER MINUTE
= LBS
RANGE = 15·3 TONS PER SQ INCH.

FIG. 15.

18th Feb. 1914

SPECIMEN W11
(ANNEALED)



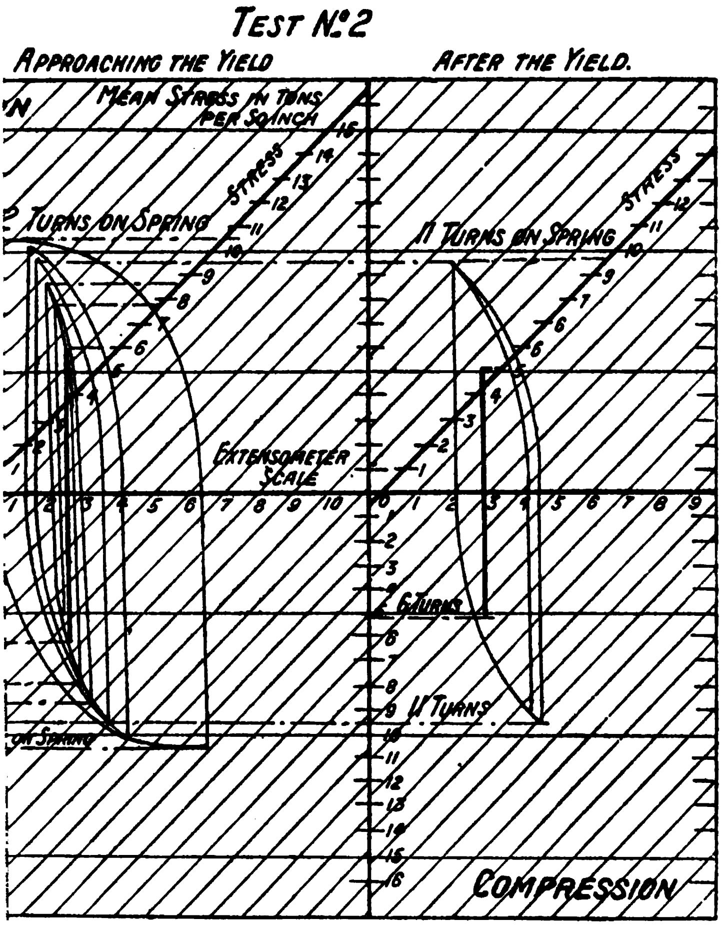
N = 486 REVS. PER MINUTE.
W = 11·46 LBS.
RANGE = 7·2 TONS PER SQ. INCH.

FIG. 18.

PLATE LI

/14

SPECIMEN G1.



EVS. PER MINUTE
LBS.

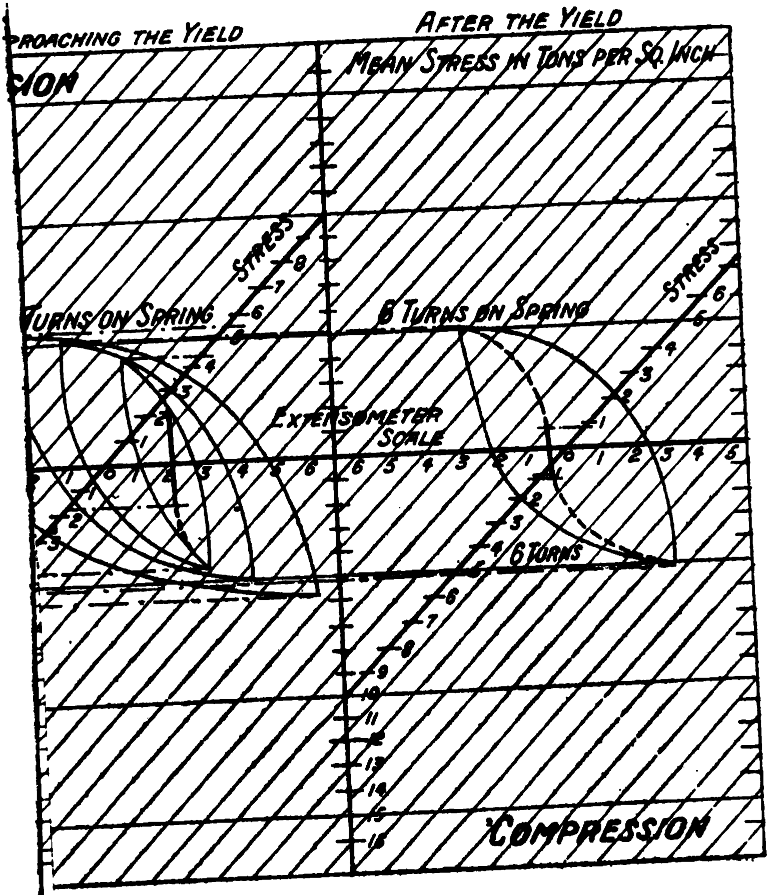
NUMBER OF ALTERNATIONS = 60,100
RANGE = 10·9 TONS PER SQ. INCH.

FIG. 21.

914

SPECIMEN G1.

TEST No. 5



0 REVS. PER MINUTE | RANGE = 18·2 TONS PER SQ. INCH

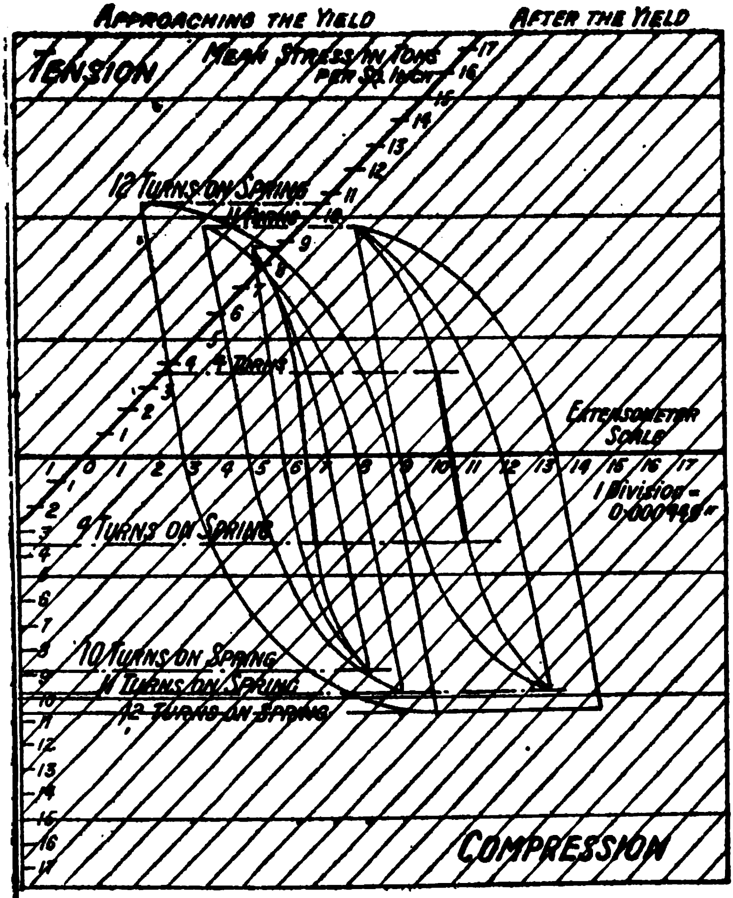
46 LBS.

FIG. 24.

May 21st 1914.

SPECIMEN G3.

TEST No 2



N = 900 REVS. PER MINUTE
W = 5·06 LBS.

LENGTH OF ILLUMINATED LINE = 8·1 CMS.
RANGE = 10·8 TONS PER SQ. INCH.

FIG. 27.

23

A

TUR

17

2

2

1½

4

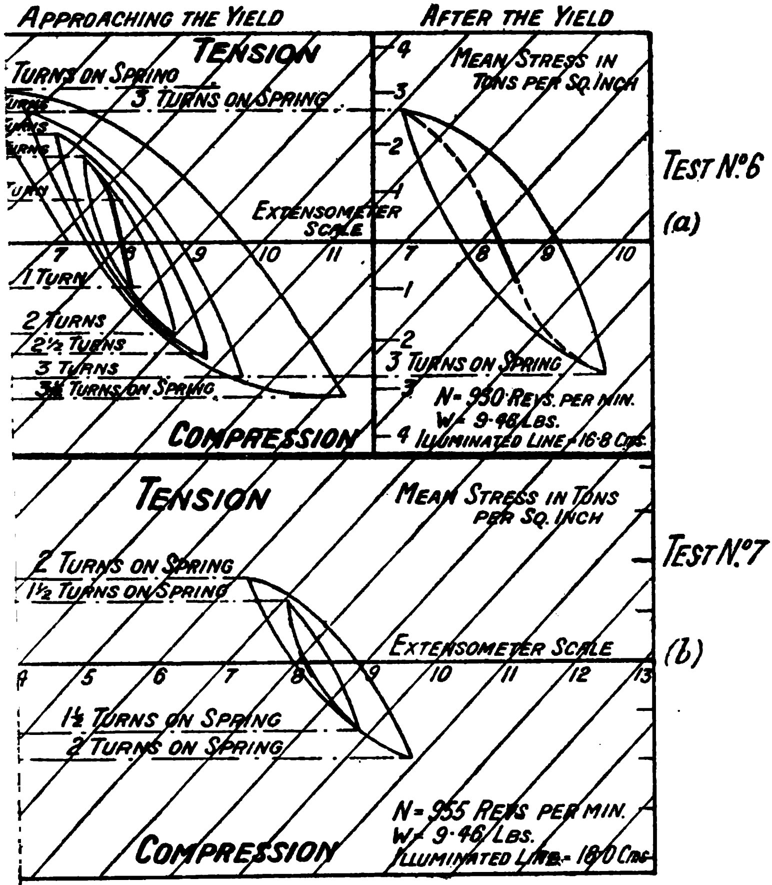
RAN

ST

23rd 1914.

SPECIMEN G3.

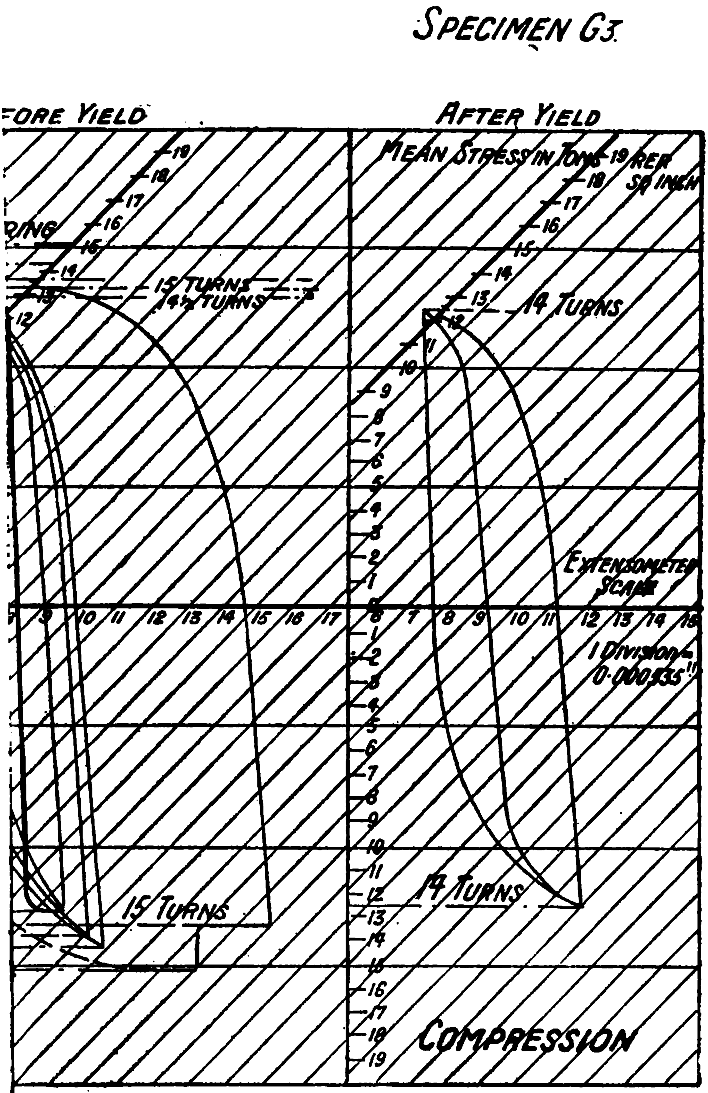
TEST Nos 6.7&8



ANGE = 21·6 TONS PER SQ IN. (b) RANGE = 22·8 TONS PER SQ. IN.

ST No 8 - For Zero Mean Stress there was practically no movement of the Line when the revolving weight of 9·46 lbs. was rotating at 980 Revs. per minute. And the Line was 20 Cms. long RANGE = 24·0 Tons per Sq. Inch.

FIG. 30.



-ER MINUTE | LENGTH OF ILLUMINATED LINE = 4·8 CMS.
RANGE = 7·2 TONS PER SQ. INCH.

FIG. 33.

tracing the straight line, and smaller loops obtained in passing through the Bauschinger state. Tables III. and IV. give the particulars of the Bauschinger ranges at the commencement of each test deduced from the curves on specimens G1 and G3.

Table II.—*Results of Experiments on Yield Ranges for Specimen G*3.

All stresses are in tons per square inch.

Test.	Periodicity.	Yield Range.	Turns on Spring.	Results Plotted in Fig. 32.		
				Mean Stress.	Maximum Stress.	Minimum Stress.
1	900	7·4	14	12·4	16·1	8·7
2	900	10·8	12	10·7	16·1	5·3
3	900	14·3	9½	8·4	15·6	1·2
4	900	18·1	7	6·2	15·3	−2·8
5	900	20·2	4½	4·0	14·1	−6·1
6	930	21·6	3½	3·1	13·9	−7·7
7	955	22·8	2¼	2·0	13·4	−9·4
8	980	24·0	0	0·0	12·0	−12·0

Table III.—*The Bauschinger Ranges for G*1.

Test.	Mean Stress Range.	Alternating Stress Range.	Bauschinger Stress Range.
1	15·2	7·7	22·9
2	12·0	10·9	22·9
3	8·0	14·3	22·3
4	7·0	16·3	23·3
5	3·2	18·2	21·4
6	0·0	19·8	19·8

Table IV.—*The Bauschinger Ranges for G*3.

Test.	Mean Stress Range.	Alternating Stress Range.	Bauschinger Stress Range.
1	10·8	7·4	18·2
2	7·2	10·8	18·0
3	5·4	14·3	19·7
4	3·6	18·1	21·7
5	2·6	20·2	22·8
6	1·8	21·6	23·4
7	0·4	22·8	23·2
8	0·0	24·0	24·0

It will be seen from the above tables that the value of the Bauschinger range obtained with gradually increasing ranges of mean stress, is practically constant for the specimen G1. In the case of specimen G3 the Bauschinger range gradually increased throughout the various tests.

It may be observed that the Bauschinger range after carrying out a yield test is always less than before the test.

An investigation was next carried out with the object of testing whether the material of specimen G3 would lead to the same results after the treatment. This treatment was certainly of a very severe nature, as the number of reversals to which the material had been subjected throughout the above series of tests was over 300,000.

TEST 9. SPECIMEN G3. FIG. 32. (PLATE LVI.)

Conditions of Test.—The alternating stress range was 7·6 tons per square inch of periodicity, 910 alternations per minute. The mean stress was varied in a cyclic manner.

It is unnecessary to tabulate the character of the variation of mean stress, for it was precisely the same as in the preceding tests. The plotted results are shown in Fig. 32.

The initial elastic line of this test is almost perpendicular to the horizontal axis. The difference in inclination between the elastic lines is due to the rest which the material had undergone during the interval of five days between this test and Test 8.

The loops traced in approaching the yield are shown in the figure; these are the loops for the limits 10, 12, 13, and 13½ turns on the spring.

The material was not loaded up to the yield; it was apparent that a yield would have occurred at the limits 14 turns or thereabouts in tension and compression, and, not wishing to take any risks, we decided to refrain from damaging the specimen further.

The Bauschinger state was then obtained by the usual systematic manipulation of the mean stress; and the line thus traced is seen to be more inclined to the horizontal axis than the initial elastic line of this test. It may be observed that the Bauschinger range obtained after yield is much less than in any of the other tests carried out in the specimen.

The result of Test 9 shows that experiments carried out on a specimen of steel which has suffered seriously, lead to yield ranges of approximately the original value.

The Effect of a Period of Rest of Eight Months on the Specimen G3.

The specimen G3 had been removed from the testing machine in the condition represented by the Bauschinger Range, Fig. 33, on the 28th May 1914. It was again locked in the machine on the 28th January 1915, with the object of discovering whether the period of rest had had any effect upon the condition of the material. The results of the following tests are rather interesting:—

TEST 10. SPECIMEN G3. FIG. 33. (PLATE LVI.)

Conditions of Test.—The alternating stress range was 7·2 tons per square inch of periodicity, 890 alternations per minute. The mean stress was varied in the usual cyclic manner. The test is a repetition of Test 1.

The method of loading is represented as follows:—

Character of Variation of Mean Stress.	Remarks on Stress-strain Curves (Fig. 33).
2 turns tension to 2 compression . .	The elastic line was traced.
4 ,, ,, 4 ,, . .	
6 ,, ,, 6 ,, . .	
8 ,, ,, 8 ,, . .	
10 ,, ,, 10 ,, . .	
11 ,, ,, 11 ,, . .	
12 ,, ,, 12 ,, . .	
13 ,, ,, 13 ,, . .	
14 ,, ,, 14 ,, . . .	Elastic limits.
14½ ,, ,, 14½ ,, . . .	The loop was traced.
15 ,, ,, 15 ,,	
15½ ,, ,, 15½ ,, . .	The loop was traced.
16 ,, ,, 16 ,, . .	
17 ,, ,, 17 ,, . . .	A yield took place.

A yield took place in tension for a mean stress of seventeen turns. The load was changed to seventeen turns in compression.

The path of the mid-point of the illuminated line was not plotted, but it is indicated by the dotted line. A yield took place for the seventeen turns limit in compression, and when the load was reduced to fifteen turns in compression the yield continued.

It became evident that the material under the previous loading of seventeen turns was in a very unstable state, and was much harder than when in the primitive state. It was also evident that it readily returned to the cyclic state when its yield had been past.

The mean stress was changed to fifteen turns in tension, and the material again yielded. The spring load was varied between fourteen turns compression and fourteen turns tension and the fourteen loop was drawn.

Comparing the results of these two yield range tests we have:—

		Mean Stress of Yield Range.
Test 1	7·4	12·4
Test 9	7·2	13·3

The close agreement of these values shows that the very severe treatment to which this material has been subjected had not appreciably affected the value of its yield ranges.

CONCLUSION.

In conclusion the authors desire to state that the curves given in the paper are chosen from a very large store of such curves obtained at various times. They have not been chosen on account of any special regularity occurring in them, but simply because they are the most complete series for single specimens in their collection.

It usually occurs in investigations of this kind that the investigator runs away from the main object of the investigation owing to certain peculiarities arising in a particular test, with the result that a great amount of time is wasted. The vexed question as to when damage is really done to the material has been investigated, and the results obtained on this point are to a certain extent wrapped up in the work here recorded. The results of the actual experiments leading to destruction, under the action of a yield range, are not, however, sufficiently far advanced to be worth placing on record, requiring as they do the investigation of loop tests corresponding to large yields.

In examining the various results given in this paper a few points stand out quite clearly, namely:—

(1) Before a yield test is carried out the Bauschinger range is always greater than it is after the test. The effect of yield is to lower the Bauschinger range.

(2) During a period of rest the Bauschinger range gradually increases, and the material slowly returns to the primitive state; it may even become harder than corresponds to this state.

(3) The Bauschinger range of the primitive state of a material is a very unstable one. This has already been pointed out by Bauschinger.

(4) If a material be subjected to alternating stress of mean stress value other than zero, and yield does not occur, the alternating stress range is an elastic range; but if a yield occurs the alternating range is not an elastic range.

(5) The yield range for a given mean stress is the maximum possible elastic range corresponding to that mean stress.

The best thanks of the authors are due to the Library and Technical Instruction Committee of the Belfast Corporation, and to Mr. F. C. Forth, A.R.C.S.I. (Principal of the Municipal Technical Institute), for the facilities which have been placed at their disposal for carrying out the work described in this paper.

THE DETECTION OF BURNING IN STEEL.

By J. E. STEAD, F.R.S., D.Sc., D.Met. (Middlesbrough).

Stansfield was the first, although it had been previously suggested by several authorities, including Mr. C. H. Ridsdale, to show clearly that the actual burning of steel, or heating it to such a high temperature as to render the metal incapable of being rolled or forged without breaking up, was coincident with incipient fusion, and I have most fully confirmed that such is the case.

In a research on a high phosphorus steel,[1] I have shown that the first liquid that forms is very rich in phosphorus, and that burnt steel can readily be detected when the metal has cooled down, for the phosphorised portions are then located either in globules or in envelopes round the crystals.

As a rule burnt steel reveals itself at the forge or rolls, and no other test is necessary to prove burning. If, however, a steel ingot, for instance, that is known to have been heated to the incipient state of fusion be allowed to cool undisturbed in the furnace, to allow the liquefied part to solidify, and then reheated again to a proper temperature, it can be rolled without breaking up, and the rolled steel will be good. This knowledge, however, is not of great practical value, for the furnaceman cannot always tell whether incipient fusion has commenced, and only discovers the fact when the metal breaks up in the mill or forge. It is of the greatest importance, however, to be able to detect with certainty whether steel has been burnt or is simply redshort.

The new departure for the detection of "burning" consists in using the new cupric reagent, described in my paper on "Iron, Carbon, and Phosphorus" (p. 140), which most clearly shows—in all steel which has broken up at the rolls or forge, as a result of what is technically called "burning"—that the phosphorus has become segregated in minute globules in the body of, and round the crystals in the form of more or less continuous envelopes.

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[1] See Nos. 35, 53, 56 in the Bibliography appended to my companion paper on "Iron, Carbon, and Phosphorus," pp. 178–181.

Heating to just below the point of incipient fusion favours the diffusion of phosphorus. If the temperature be so high that a part becomes liquid, this liquid probably corresponds in composition with the last portion to freeze in the solidifying ingot from which the forging was made, and, as has been shown,[1] this last fluid portion is always high in phosphorus. Whether, therefore, the original segregations of phosphorus of the ingot have become rolled out into threads in the forge or in the mill, or have become homogeneously distributed, it is obvious that on reheating to a temperature just above the point at which fusion commences, the first part of the metal to liquefy must contain phosphorus and carbon in large quantity.

To show that penetration of oxygen into the steel has nothing to do with burning, the following trials were made. A segregated high tensile plate was obtained containing a layer of segregate sandwiched between layers of purer material, of the following analyses:—

	Per Cent.		Per Cent.
Carbon . .	0·30	Phosphorus . .	0·067
,, . .	0·52	,, . .	0·134
,, . .	0·30	,, . .	0·067

On etching this with the new reagent the phosphorus was found to be concentrated in parallel strata, as shown in photographs 1 (*a*) and 1 (*b*); 1 (*a*) etched with the cupric reagent, 1 (*b*) etched by acid solution.

The central portion, necessarily having a lower initial melting point than the steel on each side of it, should be burnt before the purer parts outside.

The plate was slowly heated up at one end until that part actually melted. It was then taken from the fire and struck with a hand hammer. About 2 inches broke off suddenly, proving that it was technically "burnt."

In this plate, metal in all stages, from overheated to the burnt condition, was present, and with the central parts at any one point nearer to the burning point than the external portions. Sections were cut at points varying in distance from the end most highly heated, and these were etched with the acid and cupric reagents and then photographed. They are shown in photographs Nos. 2, 3, 4, and 5.

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[1] See my companion paper on "Iron, Carbon, and Phosphorus," p. 141.

Exactly what was anticipated had occurred. The globules and envelopes first appear in the central portion and the crystals are small, while the crystals in the unburnt pure part are more than twice the diameter. The purer steel at the hottest end of the plate had just begun to melt, as is indicated in photograph No. 5. The photographs Nos. 6 and 7 are of the same portion, but badly burnt. No. 6 was etched with acid reagents, and No. 7 by cupric solution.

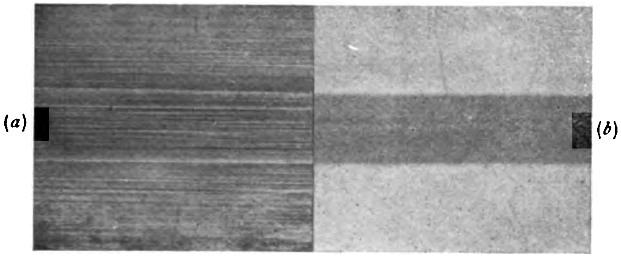
The series of photographs Nos. 14 to 17 are from a burnt ship angle which had found its way years ago into my laboratory. It was sent with the request for an opinion as to whether it had been burnt.

The photographs, with the accompanying descriptions, show what a valuable aid the cupric reagent renders to the metallographist. At one time it was believed by myself and others that oxidising gases in the furnace entered the steel and oxidised the junctions of the crystals, and that it was this oxide which made the material break up when being forged; but more exhaustive research has shown that the oxide found between the crystals is formed after the material has broken up, when air readily enters the open fissures.

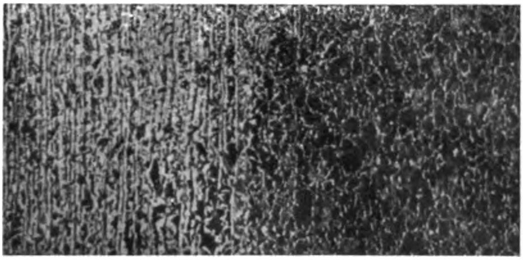
If, however, the surface layers have become liquid, the steel boils or froths, and some oxide from the surface is mechanically trapped in this liquid froth, and is found there in the cold steel.

The question is often asked of the expert, when steel samples have broken up at the rolls, whether the material is naturally redshort or has been burnt. The sides of cracks found in the steel, whether simply redshort or burnt, are always lined with oxide; and the expert, in conducting his examination, must be careful to select portions free from cracks and to polish and etch them. If they be free from globular specks rich in phosphorus, it may be concluded that the material has not been burnt and is naturally redshort, but if such specks be present the reverse conclusion will be justified.

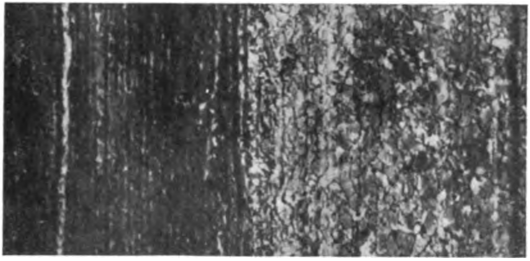
PLATE LVII



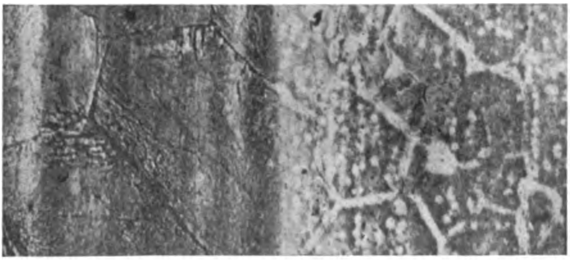
No. 1.—Tensile Plate etched (in section) by (*a*) copper solution and (*b*) acid fluid. Magnified 2½ diameters.



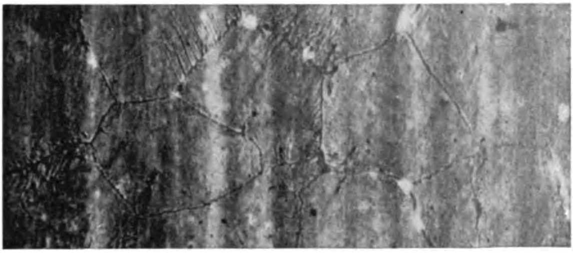
No. 2.—Same as No. 1 (*b*). Magnified 50 diameters.



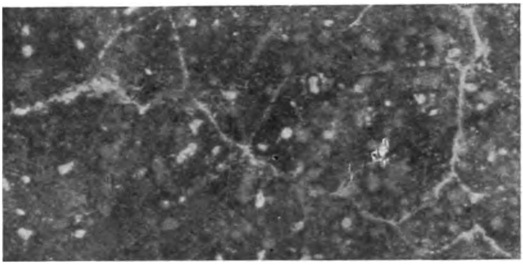
No. 3.—Same as No. 1 (*a*). Magnified 50 diameters.



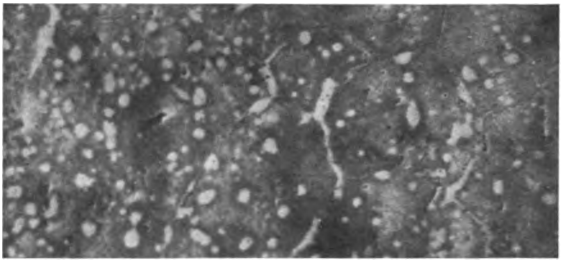
No. 4.—Heated above fusion point of segregated part but below that of purer portion. Magnified 50 diameters.



No. 5.—Purer portion of No. 1 at melting point. Etched by copper solution.
Magnified 50 diameters.

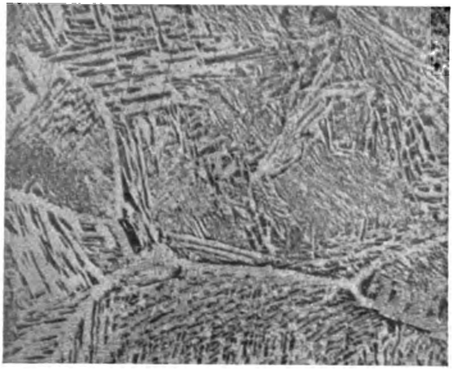


No. 6.—Same as No. 5 but more strongly heated. Etched by acid solution.
Magnified 50 diameters.

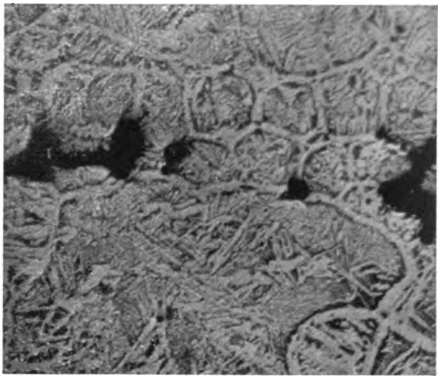


No. 7.—Same as No. 6 but etched by copper solution.
Magnified 50 diameters.

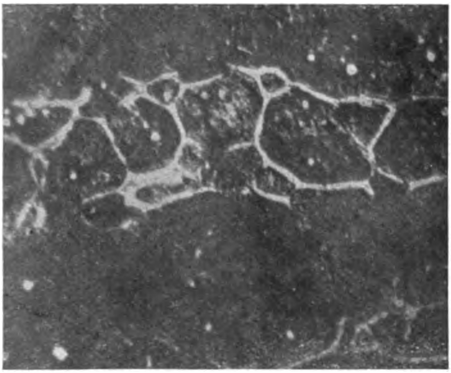
PLATE LIX



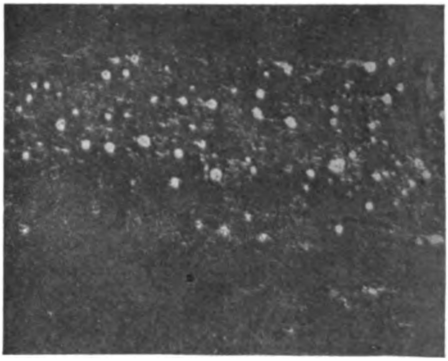
No. 8.—Phip angle, unburnt but overheated. Portion acid-etched. Magnified 50 diameters.



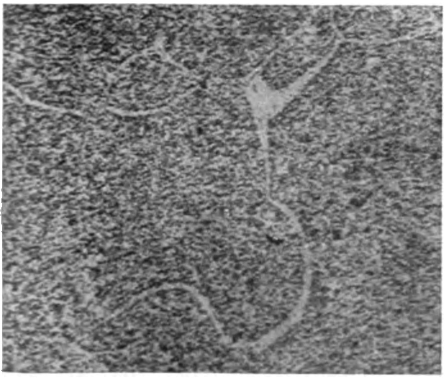
No. 9.—Same as No. 8. Slightly segregated in burnt state Magnified 50 diameters.



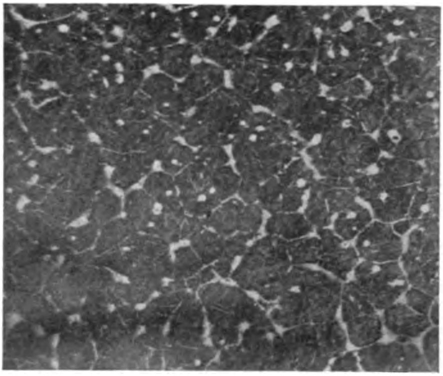
No. 10.—Same as No. 9. Copper-etched showing phosphorus. Rich areas round crystals. Magnified 50 diameters.



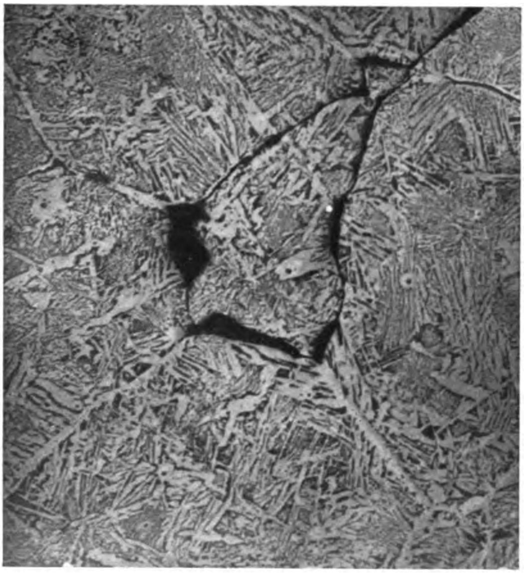
No. 11.—Another part of No. 9. Copper-etched, showing globules but not envelopes. Magnified 50 diameters.



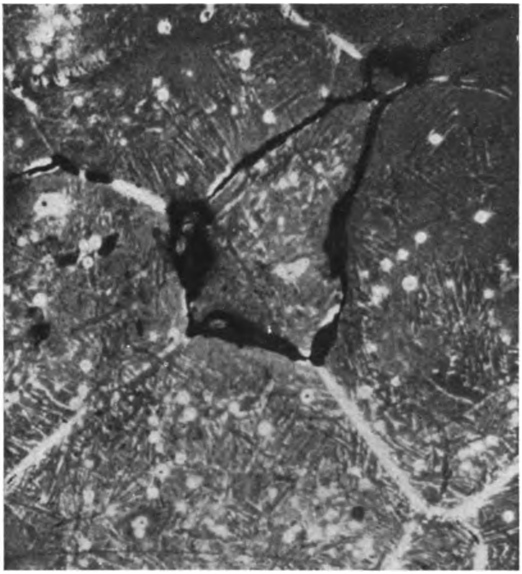
No. 12.—After re-heating at 900° and air-cooled. Acid-etched. Magnified 50 diameters.



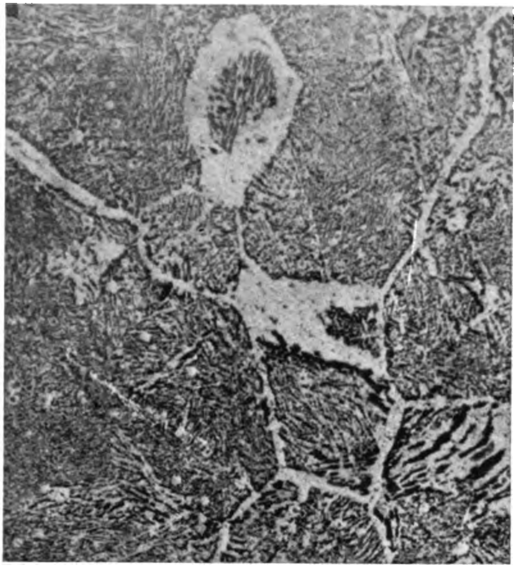
No. 13.—1·2 per cent. carbon. Sheffield steel heated to incipient fusion. Magnified 50 diameters.



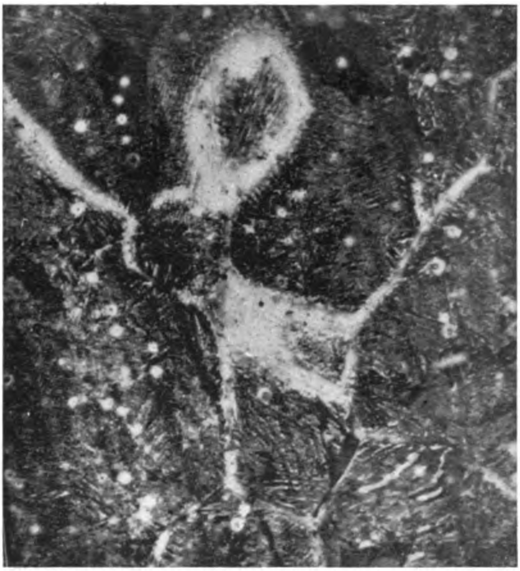
No. 14.—Burnt Steel Angle Bulb, showing spaces round crystals due to liquation. Acid-etched. Magnified 50 diameters.



No. 15.—Same as No. 14. Copper-etched, showing unliquated globules and envelopes. Magnified 50 diameters.



No. 16.—Area just below No. 15. Acid-etched. Magnified 50 diameters.



No. 17.—Same as No. 16. Copper-etched. Magnified 50 diameters.

I am indebted to Mr. W. H. Cathcart[1] of Glasgow for carrying out a large number of experiments on the burning of steel, the results of which are published in detail elsewhere.

DESCRIPTION OF PHOTOGRAPHS (PLATES LVII.–LXI.).

No. 1(*a*).—Section of a high tensile plate etched by cupric solution. Magnified 2½ diameters.

No. 1(*b*).—The same as No. 1(*a*), but etched by acid etching fluid.

No. 2.—Same as No. 1(*b*). Magnified 50 diameters.

No. 3.—Same as No. 1(*a*). Magnified 50 diameters.

No. 4.—After heating to just above the point of incipient fusion of the segregated part, but below that of the purer portion. Magnified 50 diameters.

No. 5.—The purer part of No. 1, just on the point of melting, etched by cupric reagent. Magnified 50 diameters.

No. 6.—The purer part, which had been more highly heated than the last, etched by acid reagent. Magnified 50 diameters.

No. 7.—The same as No. 6, but etched by the copper reagent. Magnified 50 diameters.

No. 8.—Unburnt but overheated portion of a ship angle, etched by acid. Magnified 50 diameters.

No. 9.—Part of same angle slightly segregated in burnt state. The black parts represent cavities. Acid etched. Magnified 50 diameters.

No. 10.—Segregated burnt part of angle etched by cupric reagent, showing globules in and envelopes rich in phosphorus round the crystals.

No. 11.—Another part of segregated portion of angle in which heating has been sufficient to form globules, but not envelopes, etched by cupric reagent. Magnified 50 diameters.

No. 12.—A part where envelopes had formed rich in phosphorus after reheating to 900° C. and cooling in air. Acid etched. Note the ferrite envelopes free from carbon. Magnified 50 diameters.

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[1] See my paper on "The Practical Use of the Iron-carbon Equilibrium Diagram, and the Burning of Steel," *Proceedings of the North-East Coast Institute of Engineers and Shipbuilders*, 1912-13.

No. 13.—A Sheffield 1·2 per cent. carbon steel after heating to incipient fusion.

No. 14.—A burnt steel bulb angle showing spaces round a crystal from which the part which liquefied had liquated. Acid etched. Magnified 50 diameters.

No. 15.—The same area as No. 14, etched by the new reagent, showing white globules and parts of the envelopes which had been liquid, but which had not liquated.

No. 16.—An area just below No. 15 into which the liquid which liquated had descended. Note the broad white ferrite envelopes and globules. Etched by acid. Magnified 50 diameters.

No. 17.—The same as No. 16, etched by the new reagent, showing that the thick envelopes and globules are rich in phosphorus. Magnified 50 diameters.

CORRESPONDENCE.

Mr. W. H. Cathcart (Glasgow) wrote that being occasionally faced with the question as to whether or not a steel forging had been burnt, he had to express his indebtedness to Dr. Stead for having developed a method of solving the problem. In a case of supposed burning, although it might be quite certain, from the fact that the operation had been personally observed, that the steel had not been heated to above the point of incipient fusion, yet experience showed the futility of attempting to refute the charge by simply asserting that the steel had not been burnt. In the cold state it was impossible to tell, from the evidence of cracks on the surface, whether the steel were redshort or burnt, since those cracks were characteristic of each. Dr. Stead had conferred a great benefit on practical workers in steel by making it possible to obtain evidence to prove whether steel that broke up while being rolled or worked under the hammer was redshort or burnt. In cases where the question was in doubt it was most desirable in the interests of all concerned that the truth should be known. The knowledge that the true cause of failure might be detected should tend to the exercising of greater care on the part of the workman, whether he be steel maker or steel user. He (Mr. Cathcart) had at different times in his experience met with redshort steel, and at the present time he had in his possession a piece of plate which in his opinion afforded an excellent opportunity for the application of the new reagent. The piece was cut from a soft steel plate $\frac{3}{16}$ inch thick, which had been bent to form a cylinder 15 inches diameter and 12 inches long. It had been welded by means of an ordinary scarf weld, 3 to 4 inches being operated on each time. Hundreds of those plates have been welded by the same expert smith without the least difficulty, but on several occasions every one of a complete batch cracked right along the entire length on each side of the welded part. When cold, there was apparently every indication of the plates having been burnt, but an attempt was made to weld some of them at the lowest possible temperature, and although the welding was successfully accomplished—as in the other instances—yet the cracks appeared in every one in parts which, while heated to above the melting-point of the sulphide of iron, were certainly not heated to above that of the phosphide and carbide of iron, a fact which might be taken to indicate that the material was redshort.

An interesting feature observed was that, with very few exceptions, the actual welded part was good, there being not the least appearance of cracking. That at first was somewhat puzzling, in view of the fact that the part to be welded was invariably heated to a much higher temperature than the adjacent parts which cracked. If the cracks were due to the material being redshort, that would be caused by the iron sulphide melting, and then adding still more to the amount of molten liquid by dissolving some of the surrounding steel, lessening thereby the cohesion between the crystal grains, and taking place with greater certainty in the parts heated to the higher temperature. If due to burning, a similar breaking up of the structure would be the result, the only difference being that in such a case phosphide and carbide of iron would become molten, and the temperature at which they did so would be much higher.

How then was the absence of cracks on the actual welded part to be accounted for? He would be glad if Dr. Stead would kindly suggest an explanation. Meantime, he would put forward the following possible solution which he had arrived at after studying the matter:—

When the plate was approaching the welding temperature, the smith habitually sprinkled sand on it in order to obtain a fusible ferrous silicate, which flowed all over the surface. On removal from the fire and during the subsequent hammering, he continued judiciously to maintain the supply of that flux. On the commencement of hammering, if the metal were redshort, separation took place between the crystal grains because of the intervening molten sulphide of iron. The iron sulphide was expelled by the continued action of hammering from the cracks which connected with the surface. On the walls of those cracks in the ordinary course, films of oxide of iron would form which would prevent them welding together again, but the supply of ferrous silicate having been maintained, no oxide could form, and if any did form, it was immediately removed in combination with the sand as ferrous silicate. The iron sulphide was therefore expelled, oxidation was prevented and coincidently the walls of the cracks, having clean metallic surfaces, were welded together as the mechanical process continued. If the above explanation were correct, it was not difficult to conceive that something of a like nature should take place in connection with burnt steel caused by heating to a temperature just above the point of incipient fusion. To investigate the matter he had carried out a few experiments. A piece of mild steel was heated just sufficiently above the point of incipient fusion to cause cracks to open up all over the surface, when it was flattened under a steam hammer. Though care was taken to ensure that the steel was not broken up too much, yet those cracks were numerous and fairly deep. Immediately after they appeared, sand was sprinkled over the steel. It was returned to the fire, more sand being used while reheating, and also during the subsequent hammering. At a temperature well under the point of incipient fusion the steel was welded at the steam hammer, and on examination when cold there was no sign of cracks. A number of pieces of steel from about 0·15 per cent. to 0·3 per cent. carbon were treated in the same way, and several which, after being flattened till cracks appeared, were then, without returning to the fire, sprinkled with sand and immediately drawn down. Every one of these pieces doubled up quite close when bent cold. The appearance of the surface of the bends proved conclusively that the cracks had all been welded. In some instances there were slight indications of cracking, but certainly not to the same extent as the initial cracks. That was, of course, to be expected since there was bound to be some of the oxide or silicate of iron not entirely eliminated. It should be noted that those faint signs of fracture developed to as great an extent in bends made from the same material without having been previously heated to above the point of incipient fusion.

It would, of course, be understood that it was not thought for a moment that those results warranted the adoption of such a practice. The experiments were undertaken simply for the purpose of confirming the explanation already given of the reason for the welded part of the plate mentioned being to all appearance quite solid when the adjacent parts were badly cracked. He would be very glad to have Dr. Stead's opinion of the matter, and also to know if he agreed with the view that the plates in question could be satisfactorily tested by the new reagent.

Mr. C. H. **Ridsdale** (Middlesbrough) wrote that the question of the burning of steel and its detection was a very important one, which arose occasionally between steel makers and users, and when it occurred they rarely agreed as to whether or not it was the steel, or the treatment by the user, that was at fault.

It was very desirable that there should be a clearer, but strictly impartial, pronouncement as to what constituted burning from a practical point of view.

There was a certain point, depending on time and temperature, to which it was legitimate to heat steel of each quality, and so long as users kept below that point, they were entitled from a commercial point of view to go as high as they wished for the convenience of their processes of manufacture, even though the temperatures they used were higher than the theoretically ideal temperatures for working. Heating beyond that point was, however, doing violence to the character of the steel, and as no maker could invest his steel with power to resist natural laws, the user was to blame if he disregarded that consideration. It was important that it should be clearly understood what that point was. As Dr. Stead had been kind enough to mention him (Mr. Ridsdale) in connection with burning, he might say that he had in the nineties, in order to study the question, made a number of experiments in overheating and burning steel, some of which were described in his paper on "Brittleness in Soft Steel."[1] As an outcome of those experiments he had in 1901[2] described rather fully the changes that occurred in steel, first as it passed from the liquid to the solid state; and conversely, when reheated until it became liquid again. In his later paper he had shown that at a point in the cooling of steel, before complete solidification, the mass consisted of a solid and a liquid, and that on heating up to the corresponding temperature, the steel became again in the same condition as it was on cooling down, that was to say, "incipient fusion."

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[1] *Journal of the Iron and Steel Institute*, 1898, No. I.

[2] *Ibid.*, 1901, No. II., "The Correct Treatment of Steel, particularly Cooling of Steel," pp. 66, 69: "Reheating of Steel," pp. 72, 73.

It was also shown clearly that redshortness (burning so that the material would not work without breaking up) occurred when the temperature approached "setting or melting point" or "incipient fusion," and Stanfield had confirmed two years later.

In that connection, and in regard to the question of the value of Dr. Stead's method for determining "when steel samples have broken up at the rolls whether the material is naturally redshort or has been burnt," there was one point in Dr. Stead's paper which he thought might with advantage be made clearer, and that was the temperature to which the presence of the globules rich in phosphorus indicated that the steel containing them had been heated, and whether Dr. Stead had definitely determined that such globules were only formed at a temperature in the neighbourhood of 1400° C. or over. Those were the temperatures he (Mr. Ridsdale) had indicated, and he believed Dr. Stead would agree with them. That was important in view of Dr. Stead's statement, "if such specks be present the reverse conclusion (burning) will be justified." From various mention of temperatures in the neighbourhood of 1000° C. as the melting point of the phosphorus eutectic, that might be misunderstood, but he was sure Dr. Stead did not suggest that heating to 1000° C. for a short time would burn ordinary qualities of soft or medium steel.

Dr. Stead's method would have a value, particularly in cases where the sample available showed none of the outside surface.

When globules rich in phosphorus were formed, their significance was, of course, that the prior work effect had been destroyed in the steel which had been heated to the temperature of the liquation of the eutectiferous mixture of phosphides, sulphides, silicates or silicides, and carbides of iron and manganese, and that the steel had received no work afterwards to again distribute and de-concentrate this. But it was essential to be clear as to whether that was necessarily burning, before the user of steel could be accused of having burnt it, simply on the evidence of Dr. Stead's method.

When the outside of the piece was available the condition of the scale was a very good index. If a sample showed cracks which had burst in rolling or forging, and the cracks contained pure scale (such as coated small sections) fused in such minute globules as to indicate that it had run "like water," it was probable that the temperature reached had been considerably above the melting point of scale, say 1400/1450° or even 1500° C. There were several other reliable indications,[1] both microscopic and otherwise—for instance, the size of grain considered in conjunction with the size of the rolled section and the probable time of heating, were efficient indications of the temperature to which the piece had been subjected;

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[1] See "Diseases of Steel," *Journal of the Iron and Steel Institute*, 1903, No. II., particularly p. 267; II. Cracks on Surface, p. 268; III. "bursts open with no coherence," p. 270; III. on overheating, "to 1400/1500° C."

whilst the thickening of the bands between the grains and the character of the structure were other indications. He (Mr. Ridsdale) would, however, utter one note of warning, and he hoped Dr. Stead would forgive him for mentioning it in connection with his method. Indications such as the subject of that paper should not alone be taken as a sure test. It was not safe to consider that if they were put into the hands of any one who had scientific training that man was qualified, on the strength of them, to pronounce whether the steel was burnt or not. It was absolutely essential that anyone, to do that fairly, should have had a large amount of practical experience, and have synthetically produced and examined burnt steels, and should also understand the practical conditions of manufacture. He felt rather strongly on that point, because there was a tendency, when some new item of scientific knowledge such as that was described, for it to be applied in far too many cases, for which it was not warranted, when looking for the cause of faults, just as the moment a new disease was discovered there was a tendency for doctors to find "every one" to be suffering from it.

What a fashion, for instance, there had been to attribute fractures and defects of almost every conceivable kind to "inclusions of dove-grey sulphide" whether there was any ground for it or not! And so probably, in spite of that warning, a number of enthusiasts who suspected burning as the cause of trouble would just look for those fused phosphide globules, and if they found any at once pronounce the sample "burnt."

On the other hand there were processes in constant use, such as drop or mechanical forging, where a piece of bar or billet was fed forward a few inches at a time, and that portion rapidly subjected to very intense heat, so that it might be forged or pressed with one blow or stroke to the required shape. The steel was intentionally brought very nearly to melting point to make it exceedingly plastic, and as it was constantly being worked just on the border line of safety it was not surprising that that line was sometimes overstepped. When that was done it was generally the steel that was blamed, and if it were desired to show that the steel had been burnt it was usually necessary to appeal to the user, not by delicate laboratory methods such as Dr. Stead's, but by indications of a more obvious and practical nature; for instance, the appearance and character of the fault (such as the burst cracks containing minute globules of fused scale already referred to; whether the piece was unsound along one edge and sound on the other, &c.)—forging or rolling tests, under watched conditions, of further portions of the same steel, &c.—see references given in foot-note to "Diseases of Steel."

What he said did not in the least detract from the great value and interest of Dr. Stead's research, for which, from the scientific point of view, he (Mr. Ridsdale) had nothing but admiration. It only showed some of the pitfalls to which too light-hearted an adoption of it as a final test, before it had been thoroughly proved, might lead.

Dr. Stead wrote in reply that he was much interested in the remarks of Mr. Cathcart, and the cases referred to in which, while the more highly heated ferrite of the weld did not break up, fracture occurred outside of the weld where the heating was not so high. The explanation given by Mr. Cathcart might be correct, but, before any definite conclusion could be arrived at, both chemical and microscopic examinations would be required. He would be glad to examine typical cases if he were provided with the specimens, together with description of the treatment. It was just such careful observations as had been made by Mr. Cathcart which often led to important revelations.

Mr. Ridsdale had long experience in the heat-treatment of steel, and his remarks on the burning of steel must be regarded with the consideration they deserved. It was quite true that in one of his early papers he had stated correctly what he conceived "burning" really meant. What he (Dr. Stead) had stated in his paper was that Stansfield was the first clearly to prove the correctness of that conception. Mr. Ridsdale asked at what temperature globular segregations of phosphorus appeared on burning steel? In general terms they appeared just above the point of incipient fusion, or above what was called the "solidus" point. That point varied with the carbon present, and might be anywhere between 145° C. and 1200° C. The carbon and phosphorus segregated together at a point just above the solidus, but when the steel cooled down the carbon diffused out of the segregated areas, leaving the phosphorus. He had no doubt that after Mr. Ridsdale's long experience, the appearance of steel which broke up on rolling was sufficient to enable him to say whether it was burnt or not; indeed, it was appearance alone on which practical men had long depended for deciding whether steel had been burnt or not. The method he had described, however, enabled one to detect burning, or whether the material had been forged or not when it had reached the point of incipient fusion.

RECENT PROGRESS IN THE DESIGN OF LARGE BLAST-FURNACE GAS-ENGINES,

WITH SPECIAL REFERENCE TO BELGIAN PRACTICE.

By Professor H. HUBERT (Liége University).

The iron and steel industries and those dealing with land and sea transport are the most important consumers of coal. This importance is shown by the fact that the world's output of pig iron in 1913 reached 80,000,000 tons. In Great Britain alone it amounted to nearly 10,000,000 tons. As it may be assumed that the coke consumption is at least equal to the tonnage of pig iron produced in blast-furnaces, and if the efficiency of the coke-oven be assumed to reach even so high a figure as 70 per cent., it will be found that the world's production of pig iron alone necessitates the annual consumption of over 110,000,000 tons.

One ton of coal transformed into coke evolves about 9000 cubic feet of combustible gas, the minimum economic calorific value of which is 350 British thermal units. On the other hand, the coke used in producing pig iron is not completely dissipated, as the gases which leave the blast-furnace contain, in addition to carbon dioxide and nitrogen, a large proportion of carbon monoxide, together with an appreciable amount of hydrogen and of hydrocarbons.

In order to avoid the charge of exaggeration, the volume of gases produced by a blast-furnace per ton of cast iron may be estimated at 14,000 cubic feet, and the calorific value at 100 British thermal units per cubic foot. · It follows, therefore, that if the manufacture of coke and cast iron alone be taken into consideration, there is produced each year a quantity of combustible gases containing potentially the enormous amount of 458,500,000 million British thermal units. The energy thus available would be completely lost to mankind if those gases were still allowed to burn freely at the chimneys of the coke-ovens and at the top of the blast-furnaces, as was done in former times. Happily the genius of inventors was early applied to the recovery of this fuel as completely as possible. The history of the economic progress realised in the production of pig iron is closely interwoven with that of the utilisation of the two kinds of gases. I have neither the time nor the intention to refer to all that has been written thereon, but shall, as a matter of fact, limit my references to the latest improvements, although by no means the least, in the applications of coke-oven and blast-furnace gases.

I may, however, be permitted to recall that until quite recent times, in fact until about the year 1895, the coke-oven gases, which were not used to heat the coke-ovens themselves, were frequently burnt under boilers in order to supply with steam the engines which served the ovens, and sometimes auxiliary motors as well. The blast-furnace gases were burned in Cowper or Whitwell stoves to heat the blast, the surplus being similarly used under the boilers supplying the blowing-engines, the hoists, and other accessory engines of the blast-furnace plant. These different applications had already effected considerable economy.

One of the most striking features of our epoch is, however, the continually increasing need of energy. It compels the engineer constantly to devote himself to the more economical utilisation of the energy available in the coke-oven and blast-furnace gases, particularly in countries which, like Belgium, have had to contend with special difficulties arising, on the one hand, from the high cost of fuel and, on the other, from the need of exporting the greater part of her products, and thus competing with countries more highly favoured by nature. The first stage in this process was the adoption of the bye-product recovery coke-oven, which enabled the valuable products formerly wasted to be obtained. These included:—

1. Ammonia, which is required in ever-increasing quantities in the alkali and other industries;
2. Benzol; and
3. Tar, from which modern chemistry successfully extracts numerous very valuable substances.

The gases being, in this manner, deprived of valuable constituents which were, however, inconvenient for the production of energy, were more easily adapted for use in internal-combustion motors, the efficiency of which is nearly twice that of the system formed by a boiler and a steam-engine. Besides this, it became possible, by adding Siemens regenerators to the coke-ovens, to utilise the heat of the waste gases, which had been employed for the distillation of the coal in the ovens, to raise the fresh gases and the air itself to a higher temperature. By this means it is possible to devote to the production of motive power and to other uses a very much larger proportion of the gases evolved during the distillation of the coal.

In blast-furnace practice the problems involved in the construction and management of the furnace have always aimed at increasing the daily production of iron and reducing the quantity of coke consumed per ton of iron made. In his Presidential Address to the meeting of the Iron and Steel Institute in 1897, Mr. E. P. Martin gave some very interesting figures relating to this question, which it may perhaps be useful to recall.

In 1791 the weekly output of pig iron of the blast-furnace in Dowlais was only 20 tons, the coal consumption being 8 tons per ton of pig iron. In 1845 the average output of each of the eighteen blast-furnaces in that region was 101 tons per week and in 1877, 260 tons, the coal consumption being 520 tons. By 1896 the weekly production had been raised to 1600 tons and the coal consumption reduced to 1½ tons of coke per ton of pig iron. Within a century the productive capacity of each furnace had been increased eighty-fold, while the coke consumption per ton had been reduced to one-sixth. As is well known, even these figures have been far surpassed, since the Duquesne blast-furnaces in the United States have actually attained to a production of 4110 tons per week, with a coke consumption of but three-quarters of a ton per ton of pig iron. This steady progress, arising obviously from a better utilisation of the coke in the furnace itself for the reduction of the ore and the melting of the metal and the slag, has naturally, as a result, reduced the amount of gases evolved per ton of pig iron, as well as the portion of combustible matter which they contain and a diminution in their heat value. For these reasons, as I have already pointed out in earlier papers, the blast-furnace gases themselves became hardly more than sufficient for the legitimate purposes they ought to serve, namely, the heating of the blast and the supply of steam to the blowing-engines.

The time was therefore ripe for the last stage, namely, the liberation of the metallurgical industry from the obligation of using a large number of low-efficiency boilers requiring a considerable area, and to set free a large amount of energy, which the iron and steel works could utilise with great economical benefit. This last stage was the practical utilisation of gases in internal-combustion engines. The problem was not an easy one to solve. Indeed, blast-furnace gas is the poorest of all power gases and may have a calorific value as low as 80 British thermal units per cubic foot, besides which it always carries a large amount of dust. Finally, blast-furnace engines are required to develop an amount of power largely exceeding that which it was possible for many years for gas-engines to develop, and in this connection it may be interesting to recall the principal stages of the development of the gas-engine.

While the invention of the gas-motor may be referred back to the commencement of the nineteenth century and attributed to the French engineer Lebon d'Hambursin, it was not until 1860 that it emerged from the experimental stage. The first gas-engine to be practically and commercially applied was that of Lenoir. This engine, which was of the double-acting type and in which the explosive mixture was fired without previous compression, bears little resemblance to the present type of engine, and its thermal efficiency did not exceed 4 per cent. I should not have referred to this engine, which has so often been described in detail, were it not that I wish to point out that, contrary to the statements made in many works, Lenoir was a Belgian who was born at Mussy-la-Ville, near Virton, in 1822, and died in Paris in 1900. I may be forgiven for pointing out that, in addition to the important contributions which my fellow-countrymen have made to the development of the power of gas-engines and of their application in metallurgy, I cannot help feeling a certain amount of pride, particularly in existing circumstances, in placing on record the fact that it was to one of that little nation likewise that the inauguration of the era of the practical application of internal-combustion engines was due. Although put together by the most skilful engineers of the period, the Lenoir engine did not realise the hopes of its inventor from the point of view of economy. As he did not adopt compression of the mixture before firing, his engine consumed far too much illuminating gas, which was the only gas then obtainable, and was very expensive. Further, it required a large amount of water and of oil, while it was unable to develop more than 3 horse-power. In spite of these defects, some hundreds were made and performed such useful services in small industries that it was possible to foresee the successful future of the internal-combustion engine, while it served also to stimulate the endeavours of inventors to improve the yield and to increase the power. Fifteen years had, however, to elapse before any further definite progress was made. It was not, indeed, until 1876 that the German engineer, Otto, invented the 4-cycle engine, in which the explosive mixture underwent preliminary compression, although as far back as 1862 the French engineer, Beau de Rochas, had pointed out with incontestable accuracy the method of working, and the advantages that would be derived, from the adoption of this type of engine. The views of this reformer were, however, neither understood nor carried out, and his memoir fell temporarily into oblivion, as had done before him the classic work of Sadi Carnot on the motive power of heat, and as the admirable invention by Tellier of the cold storage ship was destined to do later.

The Beau de Rochas-Otto cycle opens a fresh phase in the history of the gas-engine. The thermal efficiency of this engine rapidly attained to 16 per cent., thus exceeding that which the steam-engine was at this period capable of yielding. The new machine still, however, presented a good many imperfections.

1. The motor worked on the 4-cycle single acting system, the piston receiving but one impulse for two revolutions; the three other strokes of the piston were only resistant and absorbed work. On the other hand, in the steam-engine each

stroke of the piston produced motive work. As a result, and in order to develop the same power, it is necessary to increase both the dimensions and the speed of rotation in the gas-engine.

2. The motive power drops during a 2-revolution cycle from a high positive value to a considerable negative value; the turning moment is, therefore, exceedingly variable, and it is only possible to maintain a sufficiently uniform speed by employing one or even two relatively very heavy flywheels.

3. The starting of the engine is troublesome, because it is necessary to turn the wheel round until one or more explosions occur.

4. The governing is effected on the hit-and-miss principle, that is to say, by the complete cutting off of motive power once the speed exceeds a certain fixed rate, and its complete re-establishment when the speed falls below a fixed rate. It is, therefore, impossible to adjust the speed and the expenditure of fuel accurately and uniformly with the work to be done.

The steam-engine is exempt from all these defects. It is much more adaptable and lends itself to extreme variations without its efficiency suffering much. It allows of the development of considerable power and can be made rapidly to reverse by means of simple mechanism. The gas-engine had, fortunately, a high thermal efficiency, and above all it possessed the advantage of being capable of being installed wherever illuminating gas was available, without having recourse to a boiler, which is cumbrous, dangerous, and necessitates the handling of coal and ashes. Thus it soon became a serious competitor of the steam-engine in the minor industries. It would have remained within these bounds, and even been limited to towns possessing gasworks, had not an English engineer, Mr. Emerson Dowson, succeeded in liberating the internal-combustion motor from this restriction by inventing the producer, which he described at the York Meeting of the British Association in 1878.

Dowson's invention, as I have often pointed out, possesses a value, from one point of view, of the same order as that of the steam-engine itself.

The gas-producer not only liberated the internal-combustion engine from the obligation of being installed in the neighbourhood of a gasworks, but it also brought into practical use a much less expensive fuel capable of developing much greater power. It should be noted in passing that illuminating gas represents but about one-third of the weight of the coal from which it is distilled, and requires complicated operations for its purification, and the expense of distribution greatly adds to its cost. The producer, on the contrary, transforms the whole of the combustible portion of the coal into gas, requires only the minimum of cleaning, and can be built quite close to the engine. Besides this, the producer has, since its invention by Dowson, made considerable progress from various points of view. The introduction of the suction gas-producer has greatly simplified its construction, and rendered it a still more practical source for the production of motive power. That power, however, has only within recent years exceeded 300 horse-power, while, on the other hand, and this is still its weak point, it can only use certain qualities of coal. Those which are too bituminous or too dusty are unsuitable for the production of the lean gases intended to supply gas-engines. Nowadays, however, thanks to Mond, it was possible to use in large plants fairly rich coals, by recovering, in the form of sulphate of ammonia, the nitrogen content in the fuel which in other systems is lost. It is thanks to this improvement that there has been successfully installed in Staffordshire the first central power-works for the production and distribution in bulk of lean gases. According to Herbert Humphrey, this works distributes within an area of twenty-five square miles a considerable quantity of gas for the heating of furnaces and for other industrial uses, besides supplying motors and developing over 20,000 horse-power.

The developments and improvements referred to have, however, only been made gradually, so that the progress of the gas-engines has at times outdistanced that of the producer and been, so to speak, hampered by the latter. Up to 1889 it had not been possible to exceed 25 horse-power per cylinder. The important Deutz Company, founded by Otto, had not so far attempted to exceed this power in the 100-horse-power engine, exhibited in that year at Paris, which had four cylinders. At the same Exhibition a French engineer, then but little known, Mr. Edouard Delamare-Deboutteville, revealed himself as being fortunately much more adventurous. Mr. Delamare had been, to begin with, engaged in road automobile construction. Having endeavoured to achieve his object by means of steam carriages, he was naturally led to substitute for the steam-engine the internal-combustion engine, which dispenses with the use of the boiler. Aided by a skilful engineer, Mr. Malandin, he built an engine, based, like that of Otto, on the ideas of Beau de Rochas, but differing in many aspects from the Deutz engine. Mr. Delamare exhibited a specimen of this engine at Paris in 1889, coupled with a Lencauchez producer, built by the Société de la Buire, near Lyons. This engine, like the Deutz engine, developed 100 horse-power, but, and this is an exceedingly significant fact, it possessed but one cylinder, single-acting and working at four cycles. In spite of the contempt with which many engineers welcomed this plucky attempt, a contempt which I am glad to remember I did not share, and in spite of the difficulties strewn by powerful competitors across his path, Mr. Delamare-Deboutteville was not discouraged. He continued boldly to progress in the direction he had adopted and, in 1894, he succeeded in putting into operation at the Pantin Mills, near Paris, a four-cycle mono-cylindrical engine, developing 220 horse-power, with a speed of 100 revolutions only per minute.

The times were now ripe for the last stage of progress which it remains for us to consider, that is to say, the direct utilisation of the gases from coke-ovens and from blast-furnaces in internal-combustion motors. For a long time past, a number of engineers, like Lencauchez and Lürmann, had propounded the view that blast-furnaces were, as a matter of fact, large producers, but no one, prior to the stage to which reference has been made, had dared to think of using these exceedingly poor and dusty gases in so delicate an appliance as the gas-engine. When an idea has ripened, when the environment becomes favourable to its development, it frequently bears fruit simultaneously in many minds, and this is what once again now occurred. It was the late Mr. B. H. Thwaite who made the first experiments, in 1894, at the Glasgow Ironworks. This interesting attempt, which was not, however, followed up in Great Britain, does not appear to have been known to Continental metallurgists. It is, in any case, extremely remarkable that a short time afterwards experiments of the same nature were made independently of one another at Seraing in Belgium, and at Hoerde in Germany. Belgium played in the practical development of this new application an exceedingly remarkable if not preponderating part. It was, as a matter of fact, the Cockerill Company at Seraing which ventured to build, in 1897, the first large blast-furnace gas-engine, developing 200 horse-power. This undertaking was decided upon after experiments carried out on a small 8-horse-power engine, in which I myself took part with Mr. Bailly, and with which I dealt, in 1897, in the paper published in the *Annales des Mines de Belgique*, where the question was first scientifically discussed, with a clear appreciation of its future.

The importance of the Cockerill Company is well known to the members of this Institute, many of whom visited the works at their meeting in Belgium in 1913. I may in this connection remind you also of one who, for over a quarter of a century, has presided over its destinies and who, in carrying on the work of his predecessors, had brought it to so high a degree of prosperity before the terrible scourge of war came to ravage the country. It is he too who, at this crisis, has braved the storm and, even at the risk of his life, refused to yield to the threats of the invader, and, at the present moment, is still bravely struggling to maintain his works in activity and to feed the thousands of workmen who look to him for their livelihood. You will all, I feel sure, join me in paying fresh homage to him to whom your Institute awarded the Bessemer Medal, and to whom you have paid the highest honour of all by electing him as your President, Mr. Adolphe Greiner. It was he who, foreseeing a future awaiting the fresh application of blast-furnace gas, decided, on the suggestion of two of his engineers, Messrs. A. Bailly and F. Kraft de la Saulx, one of whom is still managing the workshops of the Company, to build the 200-horse-power engine of which I have spoken. For this he appealed to Mr. Delamare-Deboutteville for collaboration, and soon after, on April 11, 1898, this engine was put into operation and subjected to severe tests, during which Professor Aimé Witz and I ascertained that the gas consumption per horse-power per hour was only 3·329 cubic metres, the calorific power being 981 calories per cubic metre. It was upon these results, which assigned to the gas-engine an efficiency of 20 per cent., and showed incontestably the enormous amount of energy which could, by its means, be rendered available, that Mr. Greiner decided to build the well-known single-cylinder 4-cycle 600-horse-power engine, that was so marked a feature at the Paris Exhibition of 1900, and gained for the Cockerill Company the Grand Prize, which was the highest of the awards available.

At a period when the writers of a certain other nation are unjustly challenging the part played by Belgium in the direct utilisation of gas-furnaces, it is well to repeat the facts I have referred to. Although the Hoerde Works carried out tests on the same lines shortly after those at the Cockerill Company, and put into operation a 2-cycle Oechelhaüser engine of 120 horse-power, in 1896, and, two years later, a 600-horse-power engine of the same type but with two cylinders, the Deutz Company had built for the Paris Exhibition, in 1900, a 500-horse-power engine which preserved the 4-cylinder type, so that in reality each of the cylinders only developed 125 horse-power.

For a long time the Deutz Company only followed the bold designers of the Cockerill Company from afar. Their manager even maintained, in the columns of the technical press, that it was not reasonable to expect to exceed 350 horse-power in a single-acting 4-cycle cylinder. I drew attention in different papers and, in particular, in the note to which I have already referred, to the successive stages in the progress made by the Cockerill Company in this subject up to 1906. I will not therefore again refer to these here, but will confine myself to pointing out in the sequel the latest improvements which this Company has introduced in large horizontal gas-engines. They have produced, as may be plainly seen, an excellent type working with surety and with great adaptability. Thanks to the latest precautions which have been taken to avoid the accidents met with by all designers of large gas-engines, such as fractures of the cylinder heads, pistons, piston rods, connecting rods, and valves, and the bending and occasional breakage of crank shafts, the latest type of Cockerill engine is capable of sustaining, with advantage, any comparison with its foreign competitors. The plans and elevations which are given in the present paper, as well as the photographs which Mr. Adolphe Greiner has kindly authorised me to reproduce, afford an accurate notion of the characteristic features of this remarkable type. One of these, which is assuredly the most striking to engineers accustomed to the building of large gas-engines on the Continent, is the abandonment of the forged crank shaft and the reversion to the simple built-up crank, which had been employed by Lenoir and likewise by Otto in their earlier machines. The latter builder soon reverted to the bent crank shaft and keyed the flywheel on the overhung end of the shaft. By a sentiment of conservatism, which may be encountered at every step in the domain of engineering, as in many others, and which is indeed readily explicable in the case of gas-engines, all builders have since adopted the forged crank shaft. When the flywheel required to be made very heavy, as was the case in the earlier engines intended for the generation of electricity, its weight was distributed by placing two wheels one at either extremity of the shaft. Subsequently in large gas-engines a third outer bearing was introduced, so as to give the flywheel the support of two bearings. With this method of construction, it is evidently necessary that the three bearings should be fixed as rigid as possible and in perfect alignment, if the abnormal stress, rapid wear, and even fracture or bending of different parts of the shaft are to be avoided.

Now, the bearings which support the cranked part of the shaft are subjected to alternating stresses, the horizontal component of which is by far the most important. The bearings which support the flywheel are, on the contrary, subjected to an exceedingly heavy vertical stress. It follows that the three bearings wear in different directions and by unequal amounts. Of the two outer bearings one wears vertically and the other horizontally; the centre bearing wears obliquely. At the end, therefore, of a given period, the shaft no longer works in the original conditions for which it was calculated. It is quite easy to provide against slight wear, but it ultimately becomes impossible to readjust the shaft completely level, for it would be necessary to remove it together with the flywheel and the dynamo to which it is coupled and to turn up and true the brasses. This work, of course, is not in the nature of a running repair. In time the bearings wear until the shaft rests on the two end bearings alone and may break if it be in one piece, or become dislocated if it be built up of several parts. The conditions just explained are aggravated when the engine is subjected, as often happens in the industrial regions of Belgium, to the influence of surface subsidences caused by the working of coal-mines. It is in order to avoid these serious inconveniences that in its latest type the Cockerill Company have abandoned the bent crank shaft in favour of the shaft with an overhung built-up crank. The latter, resting on only two bearings, preserves much more rigidly the correct alignments of its axis, so that it always works under the theoretical conditions taken into consideration in the calculation of its dimensions (Plates LXII.–LXIV.).

It is to be noted that in America, which is less conservative, the same arrangement had already been for some time past adopted. The celebrated firm of Allis Chalmers, in particular, who built the important installation of the Indiana Steel Company at Gary, which comprises seventeen twin-tandem double-acting engines, capable of developing an aggregate of 51,000 horse-power, has adopted the built-up crank shaft. It may here be noted that, although embarking later than had the engineers on the Continent in the business of building large gas-engines, American practice did not fail speedily to make rapid progress. Besides the firm referred to, the American Westinghouse Company, the William Tod (Ohio) Company, and, in particular, the Snow Steam Pump Company, have designed types which diverge considerably in detail from the Continental types. The last-named firm, which has built twin-tandem double-acting units, developing as much as 5400 brake-horse-power each, has abandoned the symmetrical arrangement of the inlet and outlet valves at the two ends of the vertical axis of the cylinder. This firm places them in lateral chambers situated with a view to adopting a single foundation and bed-plate, and of allowing the cams of the distributing shaft to act directly on the valves, by simple levers and without having recourse to the long connecting-rods necessitated by the arrangement preferred by European engineers. In this, I think, the latter are right, as the stresses in the cylinder are better distributed.

Reverting to the Cockerill engines, it may be pointed out that the abandonment of the bent crank shaft and the reduction in the number of bearings to two has led the engineers of this Company to design a new form of bed-plate, which is exceedingly strong, not much raised, and presents a satisfactory appearance, as may be seen by the photographs given (Plates LXII.–LXIV.). For the more powerful types and, in particular, for the 7000 effective horse-power engine recently installed in the Cockerill Company's power-house, the bed-plate, which weighs 75 tons, is in two parts, the heavier of which weighs 50 tons. If the sections relating to the present type be compared with those shown in the paper published in the *Journal of the Iron and Steel Institute*, 1906, No. III., we find that the girder-frame system (Plate LXV.), which possessed the advantage of facilitating the overhauling of the cylinders, but was less effective than the cylindrical bed-plate in securing the distribution of the longitudinal stresses, has been abandoned.

It will be seen, likewise, that the shape of the cylinders has been improved (Fig. 1). While the longitudinal section of the older type shows clearly the projecting seat of the valve boxes, that of the existing type presents a continuous line, thus no longer showing projections where the valve boxes are situated. Besides this modification having simplified the shape and increased the strength of the cylinders, it has increased the size of the water chambers, and conferred on the cylinder walls greater elasticity to withstand the stresses arising from the differences in temperature between the outer casing and the interior cylinder. This advantage is not, of course, as is plainly evident, peculiar to the Cockerill Company's engines, but I believe that these engines are the only ones which possess steel tie-rods, which, while hot, are inserted parallel to the axis of the cylinder in the water chamber, and withstand the expansion stresses, thus causing the casting to work under compressive stresses only (Fig. 2).

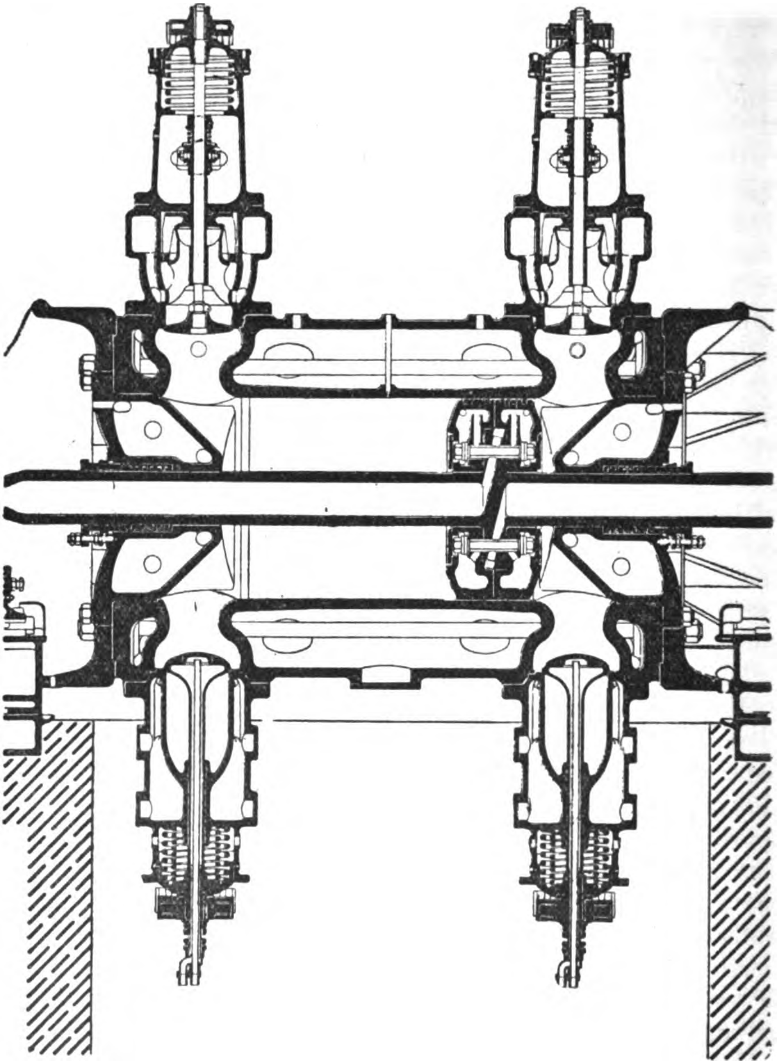


FIG. 1.—Design of Cylinders in New Form of Cockerill Engines, showing Built-up Piston.

In order to diminish the likelihood of fracture owing to the unequal dilatation of the outside and inside surfaces, and also to minimise the size of the parts to be replaced in case of accident, some engineers, like Ehrhard and Sehmer, tried building up their cylinders in several sections. I believe, however, that they have themselves abandoned this complicated construction. Others, such as Thyssen, have adhered to the single-piece cylinder, but have furnished it with an interior jacket of cast iron, which can be replaced after wear. I think, however, that this question is not one which requires to be considered in practice, as long as the lubrication of the cylinder is properly secured.

The cylinder covers and stuffing-boxes have at present very nearly the same arrangement in all the systems. In the Cockerill Company's stuffing-boxes the cast-iron packing-rings are in three parts, tightened up by a spring in the form of a band, which allows of their being renewed without uncoupling the piston rods and crosshead. The design of the pistons differs, on the other hand, considerably, according to the engines. In the principal German types the hollow pistons are in one piece, which is fitted on a tapered shoulder on the rod, and is tightened up at the back by a nut on a conical thread. It follows that, in one direction of working, the pressure on the piston acts on the rod, whereas, in the other direction, it acts upon the screw. In the system adopted by the Cockerill Company (Fig. 1), the piston is built up of two parts, bolted to a ring forged on the piston rod. Thus, whatever the direction of working may be, the piston always acts direct by pressure on the rod. The two inside walls form chambers which secure double circulation and perfect cooling of the piston. In the event of an accident, there is, generally speaking, only a half-piston to replace. Finally, the system possesses the advantage of not presenting any very great mass of metal to the action of the gas flame, and of therefore avoiding all overheating which might lead to premature explosions, which always constitute one of the most serious inconveniences in the working of large gas-engines. It follows that, whereas many engineers limit the average pressure to 4·5 kilogrammes per square centimetre (64 pounds per square inch), and are consequently compelled likewise to limit the degree of compression, the Cockerill Company can obtain an average pressure of 5·5 kilogrammes (78 pounds per square inch), while securing a high compression, which ensures a high thermal efficiency and reduces the gas consumption.

As has already been said, the different designers of large gas-engines have, for the last ten years or so, adopted, on the Continent, for the purpose of distribution, the system which consists of placing the inlet and mixture valves at the upper end and the exhaust valves at the lower end of the vertical axis of the cylinder. All the engines described in 1906, sketches of which were given in the papers by Mr. Reinhardt and myself, show this arrangement, which has its justification in the necessity for uniformly distributing the stresses in the metal of the cylinder. Besides this, all the builders had adopted adjustable admission by means of a governor, by making the latter act on the composition of the mixture, or on the weight of the mixture admitted on each stroke of the piston, and sometimes even on the two factors simultaneously.

The different systems are characterised chiefly by the number and arrangement of the inlet-valves and the method of governing.

Even at this period the Cockerill Company had adopted a trip-gear method of distribution, in which the three inlet valves for the gas, the air, and the mixture were vertically superimposed. The two latter, mounted on the same spindle, opened simultaneously a little before the commencement of the suction stroke, whereas the outlet valve still remained open. There was thus a thorough scavenging of the combustion chamber. The gas valve opened fully at a point of the stroke, which was regulated by the governor, so that the cylinder contained, to begin with, a certain volume of pure air, which followed the piston, and, later on, a mixture which, by diffusion, became richer and richer until it reached the ignition chamber, placed at the end of the cylinder. Advantage was taken of this stratification to obtain ignition even with the smallest charges, and to profit economically from the latter. It often happened, however, that misfires occurred with weak charges, and the Cockerill Company therefore reverted, in engines intended for the generation of electrical power, to quantity governing, so as to allow of varying volumes of constant composition, and so sacrificing the advantages arising from high compression in weak charges, as nearly all engine builders do.

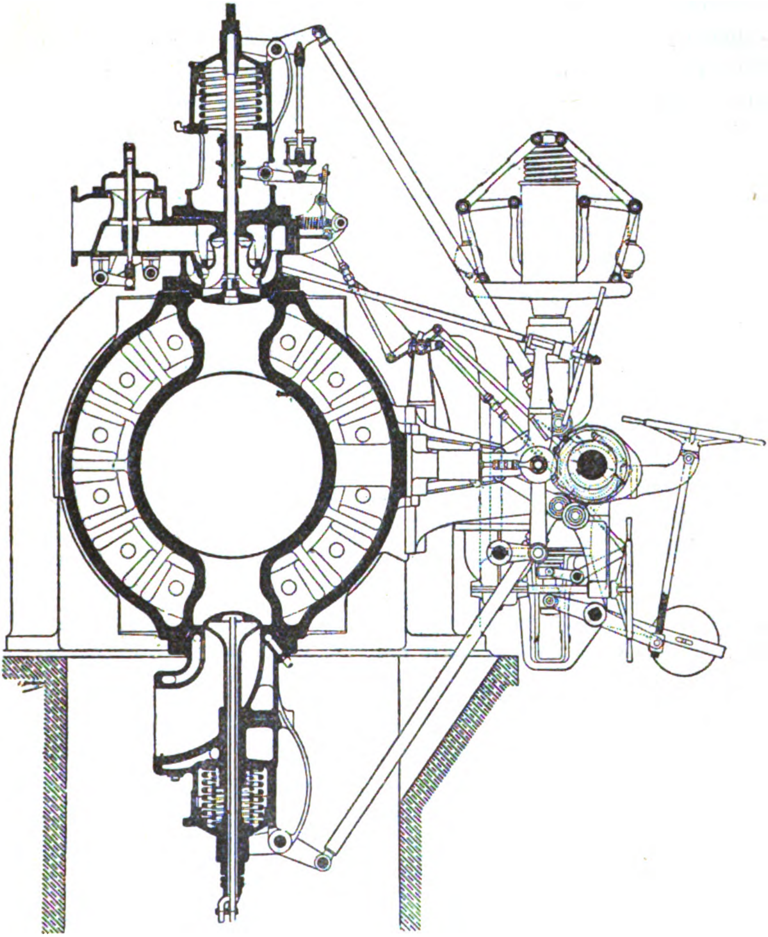


FIG. 2.—Arrangement of Mixture Valve.

They retained, nevertheless, the arrangement of the three superimposed valves, which possesses the advantage of simplicity, and the trip-gear, actuated by an adjustable connecting link, together with the interposed air-cylinder already described, which secures perfect safety in governing, comparable with that obtained in steam-engines.

In the new system (Figs. 1 and 2), the mixture valve alone opens at the commencement of the piston stroke, so that a gradually increasing vacuum is produced in the cylinder. At a period determined by the governor, the lever which controls the opening of the two air and gas valves, and which is held motionless by a stop, while pressed upon by the driving lever of the mixture valve, is freed by means of a special cam. It is then brought into motion by the action of the vacuum, which has been produced in a little cylinder interposed in the rod, which connects the two valves, and it suddenly opens the two air and gas valves, the hollow spindles of which are traversed by the spindle of the mixture valve. The air and the gas rush into the cylinder with a speed which is greater the lower the pressure, and ensures, at atmospheric pressure, its complete filling.

Other builders who had, some years ago, adopted separate boxes for the mixture, air, and gas valves, generally employ the type of combined valves used by the Cockerill Company. In order, however, to reduce the cost so as to compete successfully with rivals, many builders have simplified the distribution, either by dispensing with the air valve and making the governor act upon a throttle placed in the inflowing current of gas (Ehrhard and Sehmer), or by regulating the gas valve by hand and making the governor act on the ignition (Thyssen), or, finally, by directly governing the volumes delivered by the mixture valve and the air valve (Nuremberg). I believe, however, that the Cockerill Company is the only one employing the trip-valve gear, which works perfectly and adapts itself to wide variations in rate of speed.. When engines driving dynamos are concerned, the governing allows for a variation of ±2 per cent. in the average speed. A special mechanism allows, however, of this rate being varied by hand, during the running, from 10 to 15 per cent.

Blowing-engines have far more difficult and exacting conditions to comply with, as regards rates of speed, and, up to the present, they had not been successfully made to vary within the wide limits required in blast-furnace and steel-works prac-

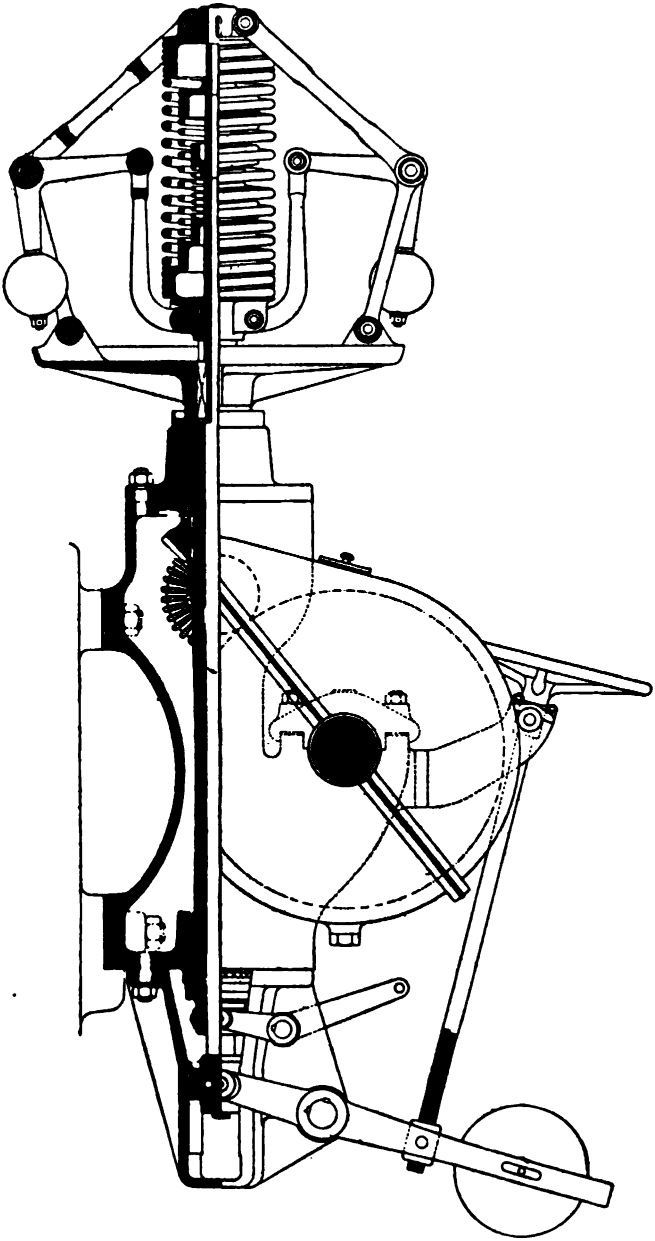


FIG. 3.—Method of Governing.

tice. The engineers of the Cockerill Company have solved the problem by means of a new system of governing, which, owing just to its exceptional application to the engines required in metallurgical operations, appears to me to deserve more than passing reference (Figs. 2 and 3).

In this method of governing, illustrated diagrammatically in Figs. 4 and 5, the governor ball is fixed at the end of a bell-crank lever jointed at the apex of the angle, the other end of which acts, by means of a connecting link, on the sleeve controlling the motion of the cam actuating the trip-gear. This sleeve acts upon a spring. The point at which the lever is jointed can, however, be placed, if desired, nearer or farther from the axis. To do this the point is carried by two connecting links, one of which is attached to a disc to which the rotary movement of the engine is transmitted by means of bevel gearing, while the other is jointed to an upper cross-piece carrying the governor spring. A hand-wheel allows this cross-piece to be lowered, and thus to vary the tension of the spring, and therefore the distance from the axis to the extreme centre of the swing of the ball. Finally, the axis of the governor carries two other springs, inside the former and shorter than it, which successively come into play when the alteration in the shape of the jointed polygon exceeds a given limit. Fig. 4 shows the forms that the polygon may assume, and, for each of them, the extreme positions of the sleeve and of the ball. Fig. 5 gives a diagram of the governing, plotted by the well-known method of taking as ordinates the height of the sleeve above its lowest position and, as abscissæ, the corresponding rate of equilibrium of the governor, regarded as a tachymeter. The four curves correspond with the four positions shown in Fig. 4. It will be seen that the mean speed may be adjusted as required to 49, 90, 126, and 162 revolutions per minute, and that in these conditions the speed of the engine may be varied, by governing, within 50, 24, 16, and 11 per cent. respectively of the mean speed. This system, as applied by the Cockerill Company to its engines, confers upon them a truly remarkable degree of simplicity, and works absolutely satisfactorily.

The ignition, which is so essential to the proper working and steady running of the engine, has been the object of special care. It has been considered advisable, not only to secure ignition, but likewise to avoid unequal stresses in different parts of the piston, to effect ignition in large engines using lean gases, at two points symmetrically in relation to the axis of the cylinder. The Cockerill Company therefore furnishes each of the double-acting cylinder covers with two potential high-induction spark igniters, an arrangement which acts better than a low potential contact breaker. On the other hand, to free the engine from all dependence on any outside source of electricity, the Cockerill Company, in contradistinction with many other builders, employs high potential magnetos, which are more expensive but more certain in their action than accumulators.

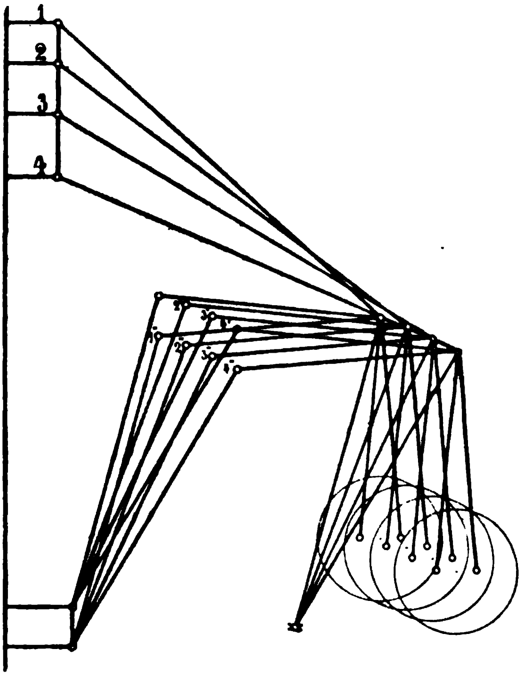


FIG. 4.—Diagram showing Action of Governor Ball.

Lubrication has also been studied with care. All the moving parts, that is to say, the pistons, the crossheads and crank-pins, the guides, and the two main bearings, are lubricated under pressure. But, whereas in many other systems the oil pump forces the lubricant into a constant-pressure reservoir, from which it drips, by gravity, on to the parts to be lubricated, the Cockerill Company furnishes its gas-engines with two plunger piston pumps, either of which would suffice to ensure service, and which force the oil directly on the parts. Lubrication is thus secured, in spite of any obstruction in the ducts, and becomes increased in proportion as the speed increases. The excess oil, before returning purified to the pumps, circulates through a little tubular cooler similar to a surface condenser.

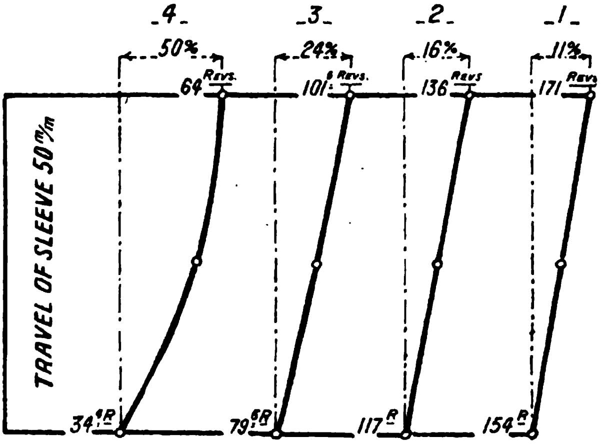


FIG. 5.—Diagram of Speed Adjustment.

Cooling, which plays so important a part in gas-engines, has been the object of no less care. The introduction of water into the piston rods is effected by means of a unique form of telescope pipe, which does away with all joints and diminishes the chance of leakage. The packing of the hollow stem of this telescopic pipe is readily accessible and can be easily tightened up during working. Further, they are cased in so that any leakage of water can be drained off without coming in contact with the bed-plate. Proper packing becomes impossible when water gets access to the jointed systems employed by many builders. In the case of leakage, piston rods unfortunately receive splashes, which interfere with the lubrication. The cooling of the exhaust valves, which is so important in the prevention of premature ignition, is carried out by means of a stream of water, which enters and leaves by armoured indiarubber piping, directly connected with fixed pipes. By this means the losses are prevented, which take place when the movable inlet and outlet nozzles fixed to the ends of the spindles of the exhaust valves are connected with fixed piping by means of packing. The cooling by the circulation of water under pressure has been extended in the Cockerill engines to the crosshead guides and to the brasses of the bearings, which are cored out. By these means the chances of the heating of important parts is reduced to a minimum.

In conclusion, it may be said that starting is effected by means of compressed air, and that a special mechanism enables the starting valves to be actuated by a single hand-wheel during the different phases of the operation, that is to say, the adjustment of the engine, its starting proper, and its normal running. This constitutes the remarkable group of well-thought-out characteristics arrived at by the engineers of the Cockerill Company, which render its latest machines models of simplicity and steadiness. Whereas in other systems there may be seen, whenever the gas supply varies, an engineer uneasily manœuvring the air and gas valves, in order to restore the proper mixture and to prevent misfires, the driver in the Cockerill engine does not touch the valves. The engine takes its full charge or a reduced charge, or even works on a vacuum without occasioning any wear; the governing and the distribution suffice automatically to maintain the best running conditions.

I will conclude this description by giving the principal dimensions of the different models from which the latest types of the Cockerill Company's engine are built:—

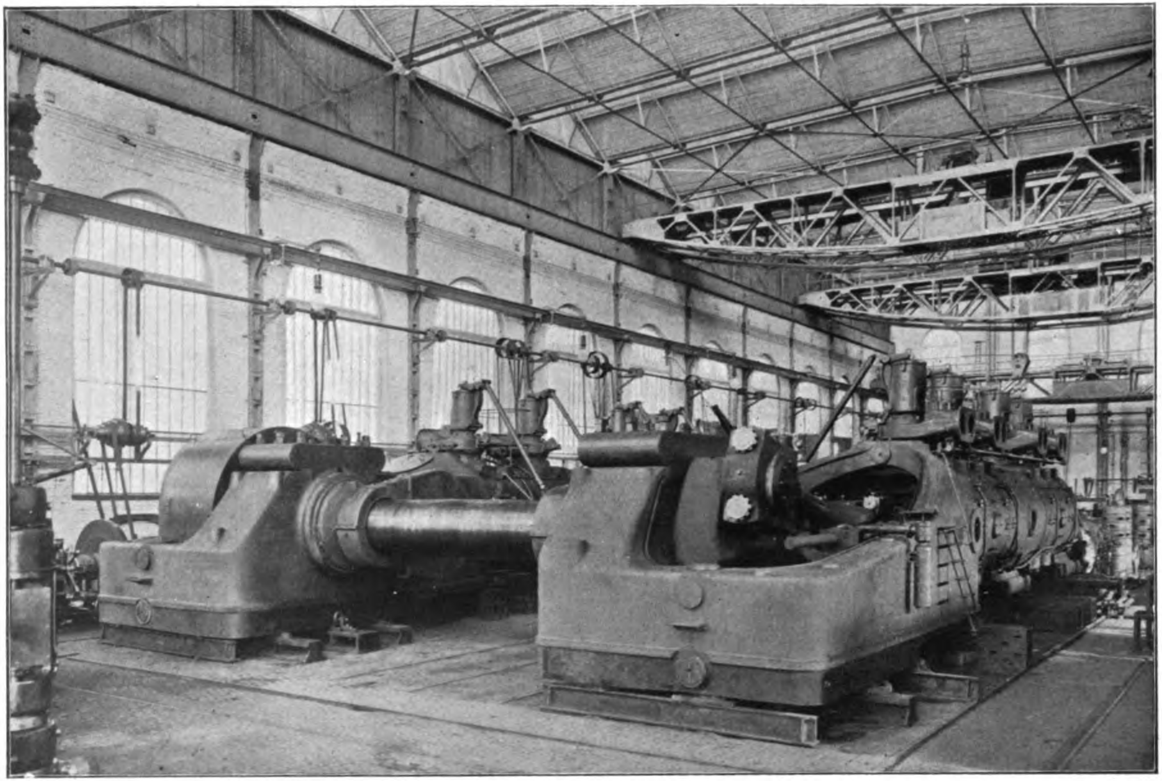
Effective horse-power—								
2 cylinders . . .	960	1250	1600	2000	2400	2825	3400	3200
4 ,, ...	2000	2500	3300	4130	5000	5650	7000	8000
Average number of revolutions per minute .	115	107	107	100	100	94	94	90
Diameter of pistons—								
In millimetres . . .	700	800	900	1000	1100	1200	1300	1400
In inches . . .	27·6	31·5	35·4	39·4	43·3	47·2	51·1	55·1
Stroke of pistons—								
In millimetres . . .	1200	1300	1300	1400	1400	1500	1500	1600
In inches	47·2	51·1	51·1	55·1	55·1	59·0	59·0	63·0

It was the last type but one, of 7000 effective horse-power, that the Cockerill Company installed in 1914 in its large central power-house. This engine, which is probably the most powerful gas-engine in the world, weighs, without its connections and the electric dynamo, 750 tons, or about 109 kilogrammes per effective horse-power. The double crank shaft which was shown at the Ghent Exhibition weighs 75 tons. It is in three pieces, the straight central portion being 1 metre in diameter, with two cranks forged together with their sockets shrunk on while hot to the two ends of the shafts.

The gas consumption guaranteed by the Cockerill Company for this type of motor corresponds to 7580 British thermal units (1910 calories) per indicated horse-power hour, and to 8530 British thermal units (2150 calories) per effective horse-power hour. The mechanical efficiency is about 89 per cent.

The consumption of water for cooling and of oil for lubrication are respectively 50 litres (11 gallons) and 1·1 gramme (17 grains) per effective horse-power hour. It is interesting to note that in the earlier experiments carried out by Mr. Witz and myself on the 200-horse-power engine, the gas consumption rose to 3260 calories, the consumption of water to 100 litres, and that of oil to 18 grammes, per effective horse-power hour. The 600 horse-power engine of the year 1900 weighed 127 tons, of which 33 tons belonged to the flywheel. This gives to the engine itself a weight corresponding to 210 kilogrammes per horse-power. These figures enable us to estimate the progress which has been made, both in regard to the power of the engines and in economy of construction and working.

PLATE LXII



7000 Horse-power 4-Cylinder (1300 × 1500) Double Tandem Engine for driving Dynamo. 94 revolutions.
For the Cockerill Company's Central Station.

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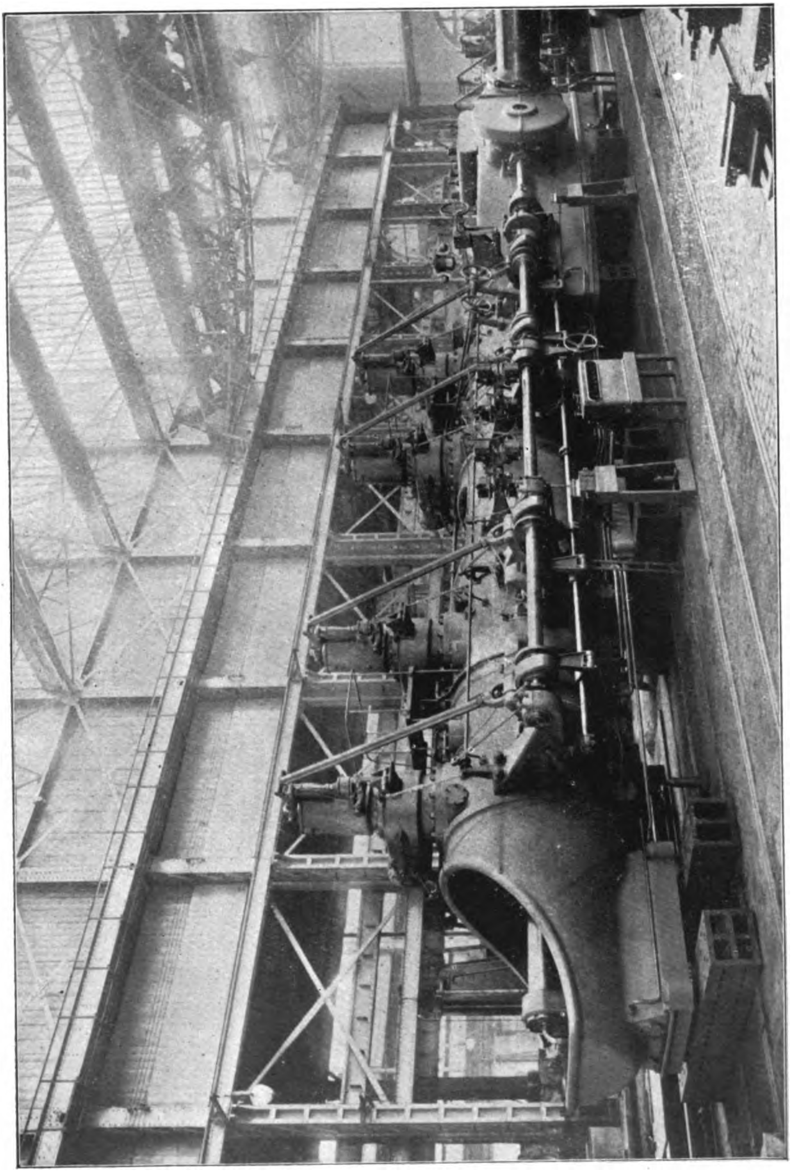

3500 Horse-power Tandem 2-Cylinder (1300 × 1500) Engine for driving Dynamo. 94 revolutions. For the Providence Works at Marchienne.

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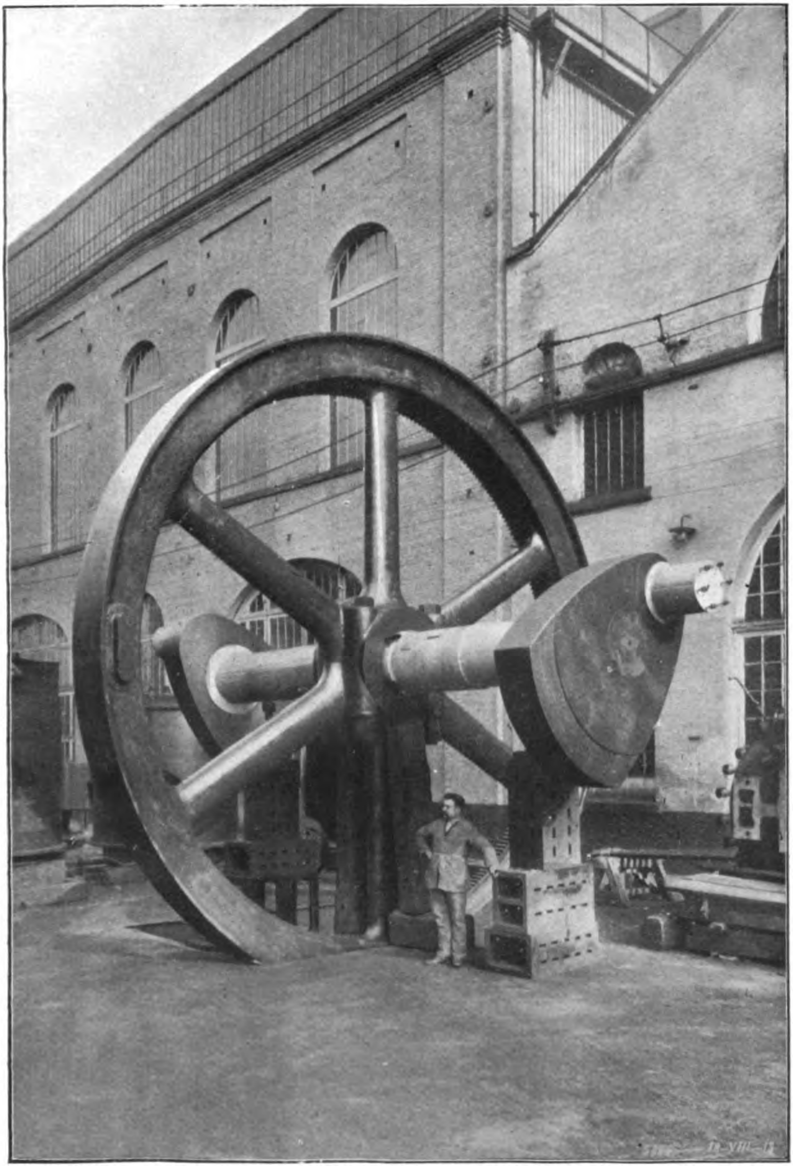

Double Crank-shaft and Flywheel for 3600 Horse-power 4-Cylinder Blowing-engine (1000 × 1400). For the Viscaya Blast-furnaces.

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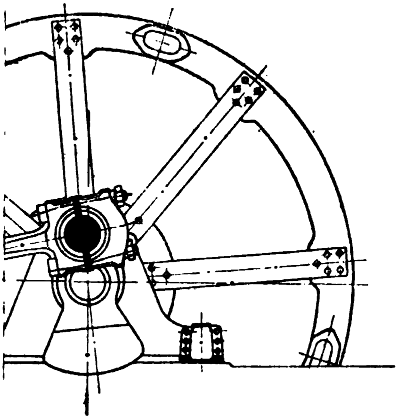
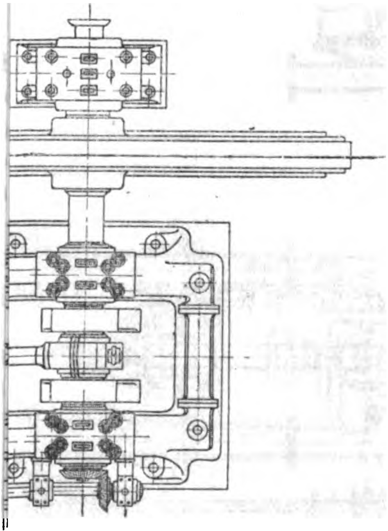


00 HORSE-POWER
TION TANDEM COCKERILL
GAS ENGINE.

Scale: 1 to 80.



Having thus described the progress and development of large gas-engines on the Continent, it would be not uninteresting briefly to refer to what has been done elsewhere. I have already mentioned that, after having hesitated somewhat to follow European engineering practice, American engineers boldly entered the field and have attained, both as regards numbers and power of their engines, an honourable position. It is, therefore, not without some surprise that we see Great Britain, which was the first country to use blast-furnace gas direct, and which possesses numerous highly skilled engineers, hesitating to embark on this industry. If part of this hesitancy be ascribed to the conservatism of the British race, it is probably no less true that the low cost of fuel which enable metallurgists to produce metal cheaply, partially explains this indifference as well. Several large firms have, nevertheless, taken up the manufacture of Continental types of engines, for which they have acquired licences, and have, in some instances, introduced interesting modifications. I may cite, in this connection, Messrs. Richardson, Westgarth & Co., Ltd., who build Cockerill engines; Messrs. Galloways, Ltd., who build Ehrhard and Sehmer engines; the Lilleshall Co., Ltd., who build Nuremberg engines, and, as regards two-cycle engines, Messrs. Mather & Platt, Ltd., and Messrs. William Beardmore & Co., Ltd., who build Koerting and Oechelhaüser engines. So far as the latter are concerned, it may be recalled that, in 1906, Mr. Reinhardt, in his paper, discussed at length the question of the relative advantages of four-cycle and two-cycle engines, and declared himself unable to come to a final decision respecting them. Although large and powerful two-cycle engines are still being built, it would appear that the advantages remain with four-cycle, double-acting engines, arranged in single or in double tandem. The eminent British engineer, Mr. Dugald Clark, who certainly cannot be taxed with partiality seeing that he is to a certain extent the father of the two-cycle engine, points out, not without surprise, in his recent treatise published in 1913, that two-cycle engines are somewhat heavier than four-cycle double-acting engines.

To revert to the gas-engines built in Great Britain, it may be pointed out that of recent years the principal firms who adopt their own special type, such as Messrs. Crossley Brothers, Limited; the Premier Gas Engine Company, Limited; the National Gas Engine Company, Limited; the Campbell Gas Engine Company, Limited; Messrs. Richard Hornsby & Son, Limited; Messrs. Tangyes, Limited; Messrs. Fielding & Platt, Limited; Messrs. Willans & Robinson, Limited, and others have built engines of ever-increasing power, although never apparently equal in size to those of the Cockerill Company, and adhering, for the most part, to engines supplied with producer-gas.

Reference should, however, be made to an original and interesting attempt to solve the problem of the building of large gas-engines on lines other than those followed by Continental engineers. I refer to the vertical multi-cylinder high-speed engines built more especially by the British Westinghouse and by the National Gas Engine Companies. These engines are composed of units compounded together and comprising each two vertical single-acting four-cycle cylinders, the pistons of which are mounted on the same rod. Each of the units drives a crank of the engine shaft. The development of power is obtained by increasing the number of units, each of which usually develops 250 horse-power. The National Gas Engine Company have attained, by this system, an output of 1500 horse-power by employing six units and consequently twelve cylinders. These engines make 200 to 300 revolutions per minute. It follows from this and from the multiplication of the cylinders that the dimensions of the latter have been able to be considerably diminished, so that it has been possible to dispense with the water-cooled piston, and to diminish the weight of the engines and also, to a noticeable proportion, the area required. According to Mr. Dugald Clark, the weight per effective horse-power of these engines is but about one-half that of large horizontal double-acting two-cylinder tandem engines. They therefore constitute serious competitors of the latter so long as the power does not exceed 2000 horse-power, as this would need twelve 26-inch cylinders, and the complication would be extreme.

So far as the iron and steel industries are concerned, it is interesting to recall that the high rate of revolution of these vertical engines allows of their being used to drive rotary blowing-engines (turbo-blowers) direct, and thus to form powerful and exceedingly compact groups. I may mention an interesting attempt of this description which was made by Mr. Hill on the furnaces of the Midland Coal, Coke, and Iron Company, near Newcastle-under-Lyme. A vertical engine of 375 kilowatts comprising three sets of two cylinders, built by the National Gas Engine Company, drives direct a rotary blowing-engine, developing a pressure of 6 to 8 pounds per square inch.

Another point of interest to note, as regards the application of blast-furnace gases in large engines, is that of the cleaning of the gases. The presence of a high percentage of dust was, in the early stages, an exceedingly serious drawback, which appeared for a time to be unsurmountable. At the present day, however, the problem has been completely solved. The use of scrubbers of different systems, of centrifugal fans, of water injection, and, in particular, of the Theisen apparatus, has for some time past allowed of the proportion of dust in the gas being reduced to 0·005 gramme per cubic metre. I should not have had to refer to this subject had I not wished to refer to a remarkable attempt to supply an alternative solution to the problem of the purification of the gas, which may, in some instances, prove exceedingly useful. I refer to the dry cleaning of the Halberg-Beth process. The British High Power Company, Limited, who build this cleaner, have installed one at the works at Newcastle-under-Lyme mentioned above. The process is too well known to need detailed description here. It may, however, be interesting to note that the plant, which is capable of cleaning 200,000 cubic feet of gas per hour, only occupies an area of 550 square feet, and the power requirement is only 20 horse-power.

According to Mr. Hill's estimates the cost of purification only amounts to £10 weekly. The method is limited to cases in which the gas does not contain any condensable tar. This is just the condition which blast-furnace gases comply with, and we may justly expect to find that dry cleaning will render valuable services to the iron and steel industries in many instances.

In conclusion, I have only to refer to the most recent improvement which has been introduced as regards the economic utilisation of blast-furnace gases. It has been in use for some little time at several Belgian and British works. In spite of the intense cold obtained by the circulation of cold water in the casing of the cylinder, in the piston and its rod, and in the exhaust valves, the gases emerge from the cylinder at a high temperature, which attains, and sometimes even exceeds, 500° C. (930° F.). If the specific heat of this gas be taken at about 0·25 and the horse-power consumption at 2·2 cubic metres of gas, requiring for further combustion 1·80 cubic metres of air, the amount of heat which is carried off in the escaping gases may be estimated at 650 calories per horse-power hour (2600 British thermal units).

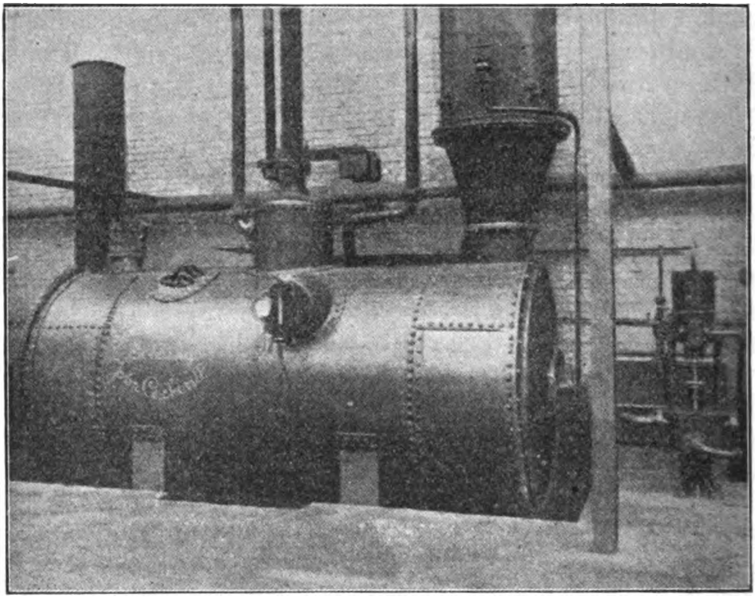


FIG. 6.—Waste-heat Boiler and Economiser.

I think about three years ago this heat was entirely wasted. In order to reduce the strident noise of the intense vibrations which the gas, issuing violently into the escapement flue, produced, water was injected into the main in the immediate neighbourhood of the outlet valve. This water formed at the outlet of the chimney a cloud of steam, which was of a nature to deceive an unwary spectator as to the nature of the engine. It was natural, therefore, to think of using the heat of this system, instead of letting it escape into the atmosphere. This final stage was achieved by the Cockerill Company. After some experiments, commenced in 1909, they settled on the arrangement shown in Fig. 6. Now, this plant consists of the addition, to the engines, of boilers, each comprising a horizontal tubular boiler, surmounted by a vertical economiser, likewise tubular. The gas, on leaving the engine at 230° C., enters the boiler, and is reduced in the economiser to 110° C., while the water is heated up from 8° C. to 170° C. The coil can be removed without stopping the working of the engine or of the boiler. The water finally passes into the latter, where it is converted into steam, to a pressure of 8 atmospheres (114 pounds per square inch).

At the present moment, four similar boilers have already been installed by the Cockerill Company for the utilisation of the heat of the gases escaped from four engines, developing an aggregate of 5000 brake-horse-power. Steam is raised in the proportion of 0·875 kilogramme (1·93 pound) per electrical horse-power of the engine, and supplies a turbine, developing about 650 horse-power. These boilers recover 55 per cent. of the heat of the gases, and increase the thermal efficiency of the engines by about 13 per cent. These figures have been supplied by Mr. Leon Greiner, in a paper read by him before the Association des Ingenieurs de Liége. The author calculates that, with an installation of four blast-furnace gas-engines, developing 10,000 horse-power, and costing £76,000, the cost of installing these recovery appliances (boilers and turbine) would be £9200. Allowing that interest and annual redemption of capital should be taken at 13 per cent., and allowing £400 as the annual cost for wages and maintenance, Mr. Leon Greiner has shown that the saving effected by recovery would amount to about £3880 per annum.

If we assume that a thermal efficiency of 30 per cent. can be obtained in the gas-engine without difficulty, we find that the latest improvement which has just been described raises this efficiency to 35 per cent., that is to say, just double that of a group consisting of high-class boilers and high-class steam-engines.

Can any further progress be made? Let us consider the question, as discussed in the latest and most important text-book by an engineer who has very greatly contributed to the progress of the internal-combustion motor, Mr. Dugald Clark. He enunciates the view that it will be possible to extend the total efficiency to within the neighbourhood of 50 per cent. by raising the average pressure, which, at the present day, cannot, without occasioning inconveniences, exceed 70 pounds per square inch, to 95 or 100 pounds per square inch, by the method of super-compressing the escaped gases.

Mr. Dugald Clark notes likewise the possibility of considerably reducing the heat losses in the walls, and cites in this connection the experiments of Professor Hopkinson, of Cambridge. He, by means of carefully injecting water into the cylinder during the compression, succeeded in rendering unnecessary the circulation of cold water in the cylinder and the piston, and of obviating therefore difficulties and inconveniences in the construction and working of large gas-engines.

All these improvements, and possibly others, such as the use of the combustion-turbine, will be the tasks of the morrow. One of them I may, however, refer to as having already been realised. In most of the existing blast-furnaces, even where the improvements described have been introduced, part of the energy contained in the gases is still wasted. On Sundays and during holidays, and sometimes even on ordinary week nights, the works associated with blast-furnaces and coke-ovens, which ordinarily consume the energy obtained by the utilisation of the gases, either are not working or require but a small proportion of the energy available. It is therefore necessary to cease its production and allow the gases to escape partly into the atmosphere, as was formerly done. During this period steam-engines work in the central power stations, and supply current to certain works and to the tramways and electrical railways, producing energy at a greatly increased cost. To avoid this waste, district power-centres are being linked up.

Such an installation already exists in Durham and Northumberland, and distributes over an area of 1370 square miles the energy produced by thirty-one steam-engines, developing 11,600 horse-power and twenty-three engines, using the waste gases from coke-ovens and blast-furnaces and developing 46,760 horse-power, making an aggregate of 162,760 horse-power.

A similar power area has been established in Westphalia, developing an aggregate of 200,000 kilowatts. Only the outbreak of the war prevented the installation in the province of Liége of a similar system developing 83,200 kilowatts. The future will see more and more of these developments, which are so valuable from the point of view of the most economical utilisation possible of the power formerly lost, and it is not without some little pride and some little emotion that in the domain of economics, as in that of politics, I may quote the noble motto of my beloved country: "Union is strength."

The conclusion of my address leads me to invoke recollections of my country, and I cannot terminate my discourse without warmly thanking the President, the Council, and the members of the Iron and Steel Institute who have so generously afforded me an opportunity of describing before so competent and learned an assembly the work of Belgian engineers in regard to a subject which possesses so high a degree of interest to the industry to which we are all devoted. I may likewise be allowed, as President of an Association of Belgian engineers in Great Britain, to thank you, on their behalf, for having so kindly invited them to attend your present meeting, and thus giving them a fresh proof of the sympathy of which we have all been so greatly the recipients since our arrival in your country.

DISCUSSION.

Mr. **Andrew Lamberton**, Vice-President, who occupied the chair during the concluding portion of the lecture, having invited any member or visitor present to express his views on the subject of the lecture—

Mr. R. B. **Slacke** said he was associated with one of the firms (Galloways, Limited) making continental engines under licence, and was therefore interested in some of the points raised. Professor Hubert mentioned that the Cockerill engine worked with a mean effective pressure of 78 lbs. per square inch. He (Mr. Slacke) wished to know whether that was a continuous load. It was the usual practice not to work above 65 lbs. per square inch continuous load, a little higher with a fluctuating load, and with momentary loads over 70 lbs., but he had never before heard of a mean effective pressure of 78 lbs. per square inch. Professor Hubert had also stated that one continental firm had given up dividing their cylinders to avoid expansion stresses. Personally he was not aware that that was the case, and would be interested to know if Professor Hubert had obtained that information recently, because a very short time previously continental firms were still making their engine cylinders in two parts, to avoid both casting stresses and expansion stresses in working—that was, they were making the jacket separately and the two ends of the cylinders separate, dividing them in the centre with a liner. The governing arrangement described was very interesting, but he would like to study it a little more closely before expressing an opinion on it. The lubrication of the Cockerill engine, as described in the paper, was, he thought, more or less standard practice for that class of engine; he did not think there was anything very novel about it. The question of the cooling of the exhaust valves was dealt with, but he believed that most continental engine firms gave up cooling the exhaust valve some years ago. He knew for certain that one firm, six or seven years before, found that in their smaller-sized engines they could dispense with cooling, and eventually in their engines of to up 1000 horse-power per cylinder cooling was similarly done away with. It would be interesting to know if the Cockerill Company still cooled all their exhaust valves. With regard to the question of further possibilities of progress, one continental firm used a scavenging system which Professor Hubert had not mentioned, whereby the output of the engine was increased 30 per cent. Air under pressure was used, and the cylinder was scavenged out after each exhaust stroke; that both cooled the cylinder and got rid of the exhaust gases, and enabled the output of the engine to be increased in the neighbourhood of 30 per cent.

The Chairman, in moving a vote of thanks to their colleague from Belgium for his interesting and instructive lecture, said it dealt with a subject with all the details of which he did not himself profess to be familiar. He felt, however, that to those interested in the subject the lecture would be extremely valuable.

The resolution of thanks having been put and carried with acclamation—

Professor **Hubert**, in reply, thanked the members for the hearty welcome that had been accorded his lecture. The members of the Iron and Steel Institute were well acquainted with his country, and especially with the Cockerill Works, which they had visited at the last meeting of the Institute in Belgium. The Cockerill Works were founded a century ago by an Englishman, and it was well to bear in mind that, even in those bygone days, cordial feelings existed between the little Belgian nation and the great British nation, which was Belgium's natural defender. Most of the members who visited the Cockerill Works would remember that on the walls of the large gas-engine house of the works the arms of the Cockerill Company had been placed. Those arms consisted of a red cross with a cock crowing over it, and the noble device, "Courage to the last." He believed that device would prove truly and nobly prophetic.

RECORD OF THE DISCOVERY OF THE INFLUENCE OF VANADIUM ON STEEL.[1]

By J. O. ARNOLD, D.Met., F.R.S.
(Professor of Metallurgy at the University of Sheffield).

INTRODUCTORY NOTE.

In the spring of 1899 the late Mr. August F. Wiener called upon the author with an introduction from the Chairman of the Applied Science Committee of the University College of Sheffield.

It transpired that Mr. Wiener was interested in a lead-silver mine in Spain, in which had been discovered a vein containing about 13 per cent. of oxide of vanadium. He wished to know if anything was definitely known as to the influence of vanadium on steel, as the syndicate of which he was the managing director had established a small works at Llanelly in South Wales for the production of metallic vanadium. The author informed Mr. Wiener that so far as he knew there was no definite data as to the influence of vanadium on steel, but that if pure 33 per cent. ferro-vanadium could be produced and supplied free of cost to the metallurgical department of Sheffield College, he would undertake a research, and report the results to the vanadium syndicate. The latter accordingly during the next three years or so, from time to time, presented to the College ferro-vanadium of a total value of about £100. The author made a proviso that the results, if favourable, should, in the first instance, be communicated only to Sheffield steel manufacturers, but a stray copy of the first report got abroad, and a foreign firm deleted the name of the British syndicate, inserted their own, and widely distributed the report as having been made to them. The succeeding reports were, therefore, copyrighted at Stationers' Hall.

In 1904, in *The Engineer*, Mr. Wiener, with the author's consent, published a somewhat lengthy abstract of the results of the experiments, and it was thought that it might now be well as a matter of some historical interest to publish the original reports in the *Journal of the Iron and Steel Institute.* It may also be remarked that the results obtained in the crucible were confirmed in the 2-ton open-hearth furnace in the then Sheffield University College.

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[1] Printed by order of the Council of the Iron and Steel Institute as a subject of historic interest.

The sudden and untimely death from influenza of Mr. Wiener just when the value of vanadium as a steel-making element began to be fully appreciated, was keenly regretted by all who had known him intimately.

REPORTS OF ORIGINAL INVESTIGATIONS ON THE INFLUENCE OF VANADIUM ON STEEL.

FIRST REPORT.

University College, Sheffield,
June 28, 1900.

AUG. F. WIENER, Esq.,
The Alloys Syndicate, Ltd.,
31 Lombard Street, London, E.C.

Dear Sir,—With reference to my investigation as to the mechanical influence of the metal vanadium on iron and steel, I have to report as follows:—

Six ingots were made by the ordinary crucible process. Of these ingots one was pure Swedish iron, and the other five were steel melted from No. 4 converted Swedish bar. In the finished bars the silicon averaged 0·1, the sulphur 0·035, the phosphorus 0·015, and the manganese 0·05 per cent. The vanadium was added by means of three samples of ferro-vanadium (also containing aluminium) supplied by you with their approximate analyses. The ingots were rolled to ¾-inch round, and the bars were tested in tension.

The results of the melting experiments and the mechanical tests are embodied in the table on following page.

Consideration of Chemical Results.

The tabulated figures indicate that the approximate analyses of the alloys supplied by you somewhat understated the

Tables of Chemical and Mechanical Results.

CHEMICAL RESULTS.							MECHANICAL RESULTS.			
Ingot No.	Combined Carbon per Cent.	Vanadium per Cent.	Aluminium per Cent.	Calculated Vanadium per Cent.	Calculated Aluminium per Cent.	Remarks, Alloy added.	Elastic Limit, Tons per Square Inch.	Maximum Stress, Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.
617	1·06	0·14	0·07	0·12	0·04	11 mins. before teeming	43·0	67·9	6·5	6·9
618	1·02	0·29	0·09	0·50	0·53	with charge	43·2	76·2	8·5	10·0
619	1·00	0·58	0·36	0·50	0·53	21 mins. before teeming	64·8	85·5	7·0	7·6
620	0·05	0·85	0·05	1·00	0·12	12 mins. before teeming	20·4	26·1	37·0	72·0
621	0·80	1·11	0·45	1·00	0·33	10 mins. before teeming	54·0	77·1	10·0	17·6
622	1·04	0·77	0·21	1·00	0·92	with charge	58·8	84·0	7·5	9·3

percentage of vanadium and aluminium really present. These discrepancies, however, do not seriously affect the broad issues determined by the experiments. It is evident that when the triple alloy is added with the main charges, most of the aluminium, and, roughly, 30 per cent. of the vanadium present, are removed by oxidation. On the other hand, when the alloy is added, say fifteen minutes before teeming, the whole of the vanadium and aluminium present pass into the steel. It is therefore very desirable that you reduce the aluminium in the alloy to, say, 1 per cent.

Consideration of Mechanical Results.

The results of the mechanical tests prove beyond doubt the remarkably powerful influence of vanadium on iron and steel. A pure iron ingot without vanadium yields a bar having an elastic limit of 12 tons and an ultimate stress of 21 tons per square inch, and also a reduction of area of about 75 per cent. Therefore 0·85 per cent. of vanadium has raised the elastic limit 8 tons and the ultimate stress 5 tons per square inch without practically reducing the ductility. But its influence on iron is not nearly so extraordinary as its action on the alloy of iron and carbon known as steel.

A nearly pure iron and carbon steel containing about 1·10 per cent. of carbon has an elastic limit of about 30 tons, an ultimate stress of about 60 tons per square inch, together with an elongation on 2 inches, and a reduction of area of each about 8 per cent. On reference to the table, it will be seen that, without practically altering the ductility, 0·14 per cent. of vanadium has raised the elastic limit 13 tons and the maximum stress about 7 tons per square inch.

Then, without lowering the ductility (if anything, raising it), 0·3 per cent. of vanadium lifts the stress to 76 tons, and 0·6 per cent. raises it to 85 tons per square inch. There seems to be no advantage in adding beyond 0·6 per cent., as the steel containing 0·77 per cent. gave practically the same results as that containing 0·58 per cent. of vanadium.

The elastic limit of nearly 65 tons per square inch possessed by the steel last named is more than remarkable.

Hardened Vanadium Steel.

The foregoing mechanical results suggested that the steel when made into drills and hardened and tempered would exhibit extraordinary cutting power. A drill from bar No. 618 (in which the aluminium present could not appreciably affect the results) was tested against a special quality drill containing 1·2 per cent. of carbon and 3·0 per cent. of tungsten. It was found that the vanadium tool hardened well at a very low, in fact hardly visible, red heat. A drill was broken after hardening, and exhibited a superb fracture showing practically perfect homogeneity. The drills (3·0 per cent. tungsten and 0·3 per cent. vanadium) were tried dry on a slab of chilled white iron. The drills, which were of the same pattern, were each worked at their full cutting power for ten minutes and the resulting drillings were weighed. The vanadium drill had removed 3½ against 2 ounces removed by the tungsten steel.

The results of this preliminary investigation have profoundly impressed upon my mind the future before vanadium as a steel-making element, and even at this early stage of my knowledge of its effects, I venture to say that its action resembles that of tungsten, but that it is from ten to twenty times as powerful as the latter element.—I remain, dear Sir, yours faithfully,

J. O. ARNOLD,
Professor of Metallurgy.

SECOND REPORT.

UNIVERSITY COLLEGE, SHEFFIELD,
January 14, 1902.

A. F. WIENER, ESQ.,
VANADIUM ALLOYS, LIMITED,
LOMBARD STREET, LONDON.

DEAR SIR,—With reference to the experiments made (with the 33 per cent. pure ferro-vanadium supplied by your company) to ascertain the influence of the element vanadium on ordinary mild steel and on mild nickel steel, I have to report as follows:—

Method of Manufacture.

The ingots were made by the usual crucible process. They weighed 50 lb. each, and were cast into 3-inch square moulds.

Chemical Composition.

The five experimental ingots had the chemical compositions embodied in the following table:—

Mark.	Carbon per Cent.	Vanadium per Cent.	Nickel per Cent.	Silicon per Cent.	Manganese per Cent.	Sulphur per Cent.	Phosphorus per Cent.
682	0·22	none	none	0·083	0·24	0·02	0·015
683	0·20	0·27	none	0·092	0·48	0·02	0·015
684	0·25	none	3·35	0·084	0·46	0·02	0·015
685	0·24	0·28	3·38	0·091	0·48	0·02	0·015
695	0·18	0·61	none	0·148	0·43	0·02	0·015

As far as carbon, silicon, manganese, sulphur, and phosphorus are concerned, the ingots were practically of identical composition, except that 682 were lower in manganese, and 695 higher in silicon than was intended. I do not think, however, that in the case of such mild steel these discrepancies can affect the mechanical results to any important extent.

Forging and Rolling of Ingots.

The four ingots 682 to 685 inclusive were cut into two parts. In every case one half was hammered and rolled into a ¾-inch round bar, the other half being rolled into a 3-inch by ⅜-inch plate. One half of ingot 695 was rolled into a 3-inch by ⅜-inch plate. The working of the steels under the hammer and in the rolls left nothing to be desired.

Mechanical Tests.

The results of the tensile tests are set forth on the accompanying record sheet. The letter "N" (normalised) indicates that the test-bars so marked had, after leaving the rolls and becoming cold, been reheated to 800° C., and then allowed to cool in air. All the other tests have reference to the materials as received from the rolls.

Discussion of Tensile Results.

682. The ordinary steel 682, as it left the rolls, recorded an unusually high elastic limit in the round bars, but a normal limit in the plates. I am unable to account for this, but call attention to the fact.

683. The ingot 683, to which a calculated amount of 0·3 per cent. of vanadium was added, was found by analysis to contain 0·27 per cent., and to this relatively small quantity must be substantially attributed the difference in mechanical properties from those of the plain steel 682. These differences may be summarised as follows: The 0·27 per cent. of vanadium has raised the elastic limit 12 and the maximum stress 16 tons per square inch. This remarkable increase in tenacity is accompanied by a fall of 11 per cent. in the elongation and of 9 per cent. in the reduction of area. The loss of reduction of area is small compared with that of elongation, a fact showing that the decreased ductility is more apparent than real as being due, not to hardness, but rather to most of the elongation being concentrated about the point of fracture instead of being distributed over the test bar in the usual proportions.

684. The nickel steel 684 presents the usual mechanical properties of such material.

685. The vanadium nickel steel 685 shows in a startling manner the powerful effect of about 0·3 per cent. of vanadium on ordinary mild nickel steel. The relatively small quantity of vanadium has raised the elastic limit 18 and the ultimate stress 26 tons per square inch. A steel having an elastic limit of 50 tons, a maximum stress of nearly 70 tons, and at the same time an elongation of nearly 17 and a reduction of area of nearly 40 per cent. is, to say the least, a most remarkable metal.

The Normalised Rolled Bars.

These tests show that vanadium steel is sensitive to thermal treatment, the specified heat treatment having considerably lowered the elastic limit and maximum stress, and somewhat raised the elongation and reduction of area per cent.

The Plate Tests.

Taken as a whole, these tests confirm the results obtained from the bars. A comparison of the figures recorded for plates 683 and 695 show the effect of raising the percentage of vanadium from about 0·3 to about 0·6 per cent. The additional vanadium has lifted the elastic limit 7 and the maximum stress 10 tons per square inch. The elongation remaining practically unaltered, and the reduction of area falling only about 7 per cent., I shall send later a set of tests obtained from oil-quenched bars, from which interesting results may be anticipated.

Bending Tests.

The results of the bending tests made on the set of steel plates are recorded in the following table :—

Mark.	Size.	Bent Cold over a Radius of	Bending Angle.	Remarks.
682	12-inch × 1-inch × ⅜-inch	⅜-inch	180° unbroken	Closed without fracture.
683	,, ,, ,,	,,	,, ,,	Broke on closing ; steel much stiffer than 682.
684	,, ,, ,,	,,	,, ,,	Cracked on closing.
685	,, ,, ,,	,,	120° broke	Steel very stiff.
695	,, ,, ,,	,,	180° unbroken, very stiff	Broke on closing.

Summary of Tests.

It is already evident that as a steel-making element vanadium will place in the hands of metallurgists and engineers a very powerful weapon, because it is now demonstrated beyond doubt that the addition of a few tenths per cent. of vanadium raises the elastic limit of mild structural steels at least 50 per cent. without seriously impairing its ductility or presenting any difficulty in the hot or cold working of the steel.

The Chemical Action of Vanadium on Steel.

In my opinion there is no reasonable doubt that vanadium exists in steel in a double carbide of iron and vanadium. On dissolving such steel in dilute sulphuric acid, most of the vanadium present is found in a dark, insoluble, and somewhat voluminous residue containing also iron and carbon.

The Micrographic Influence of Vanadium.

Micrographic sections were cut from 682 and 683 round bars, and were polished, etched, and photographed at a magnification of 360 diameters. The above photomicrographs are sent herewith. It will be noted that as usual in the ordinary steel the iron and true steel, otherwise ferrite and pearlite areas, have sharply segregated (the ferrite is the pale and the pearlite the dark constituent). In the vanadium steel, however, the constitutional segregation has been greatly retarded, the carbon is more evenly distributed throughout the mass, and the two constituents present no sharp lines of demarcation. The characteristic last named may turn out to be of great importance, because at the present time it is of vital importance to obtain a structural steel incapable of deteriorating and fracturing under vibration, and the structure of the vanadium steel is of the type most capable of resisting vibratory fracture. The respective micro-sections present marked resemblances to mild steel before and after oil quenching, and I am of opinion that the action of vanadium may be briefly described by the statement that it acts automatically in the same way that the operation of oil quenching acts.—I remain, dear Sir, yours faithfully,

J. O. ARNOLD,
Professor of Metallurgy.

APPENDIX TO PROFESSOR ARNOLD'S REPORT TO VANADIUM ALLOYS (1901), LTD., LONDON, *dated* 14*th January* 1902.

METALLURGICAL DEPARTMENT, UNIVERSITY COLLEGE, SHEFFIELD.

Testing Sheet.

No.		Before Fracture.			Elastic Limit.		Maximum Stress.		After Fracture.			Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.
		Diameter, Ins.	Length, Ins.	Area per Sq. In.	Tons on Section.	Tons per Sq. In.	Tons on Section.	Tons per Sq. In.	Diameter, Inch.	Diameter, Ins.	Area per Sq. In.		
	Nos. 682 to 685 were hammered and rolled into ⅝-inch round bars.												
682	Plain steel; no V; C, 0·22; Mn, 0·24	0·564	2·00	0·25	6·43	25·72	7·66	30·64	0·356	2·67	0·0995	33·5	60·1
683	V, 0·27; C, 0·20; Mn, 0·48 . .	,,	,,	,,	9·35	37·40	11·77	47·08	0·393	2·44	0·1213	22·0	51·4
684	No V; Ni, 3·35; C, 0·25; Mn, 0·46	,,	,,	,,	8·15	32·60	10·55	42·20	0·387	2·53	0·1176	26·5	52·8
685	V, 0·28; Ni, 3·38; C, 0·24; Mn, 0·48	,,	,,	,,	12·57	50·28	17·04	68·16	0·450	2·34	0·1590	17·0	36·3
	Nos. 682 N to 685 N are the same bars as above but normalised.												
682 N	Plain steel; no V; C, 0·22; Mn, 0·24	,,	,,	,,	5·79	23·10	7·08	28·32	0·336	2·75	0·0886	37·5	64·5
683 N	V, 0·27; C, 0·20; Mn, 0·48 . .	,,	,,	,,	7·05	28·20	9·06	36·24	0·359	2·59	0·1012	29·5	59·4
684 N	No V; Ni, 3·35; C, 0·25; Mn, 0·46	,,	,,	,,	7·91	31·64	10·27	41·08	0·370	2·57	0·1075	28·5	56·9
685 N	V, 0·28; Ni, 3·38; C, 0·24; Mn, 0·48	,,	,,	,,	11·58	46·32	13·60	54·40	0·394	2·44	0·1219	22·0	51·2
	Nos. 682 to 685 and 695 were rolled into 3-inch by ⅜-inch plates . .	...	2·00	...	...	...	...	...	0·705 ×	2·84	...	42·0	...
682	Plain steel; no V; C, 0·22; Mn, 0·24	1 × 0·355	4·00	0·355	6·84	19·26	10·13	28·53	0·244	5·24	0·1720	4″ = 31·0	51·5
			2·00						0·785 ×	2·38		19·0	
683	V, 0·27; C, 0·20; Mn, 0·48 . .	1 × 0·363	4·00	0·363	12·25	33·74	16·07	44·27	0·270	4·68	0·2119	4″ = 17·0	41·6
			2·00						0·760 ×	2·36		18·0	
684	No V; Ni, 3·35; C, 0·25; Mn, 0·46	1 × 0·363	4·00	,,	9·70	26·72	14·60	40·22	0·284	4·85	0·2158	4″ = 21·2	40·5
			2·00						0·940 ×	2·20		10·0	
685	V, 0·28; Ni, 3·38; C, 0·24; Mn, 0·48	1 × 0·363	4·00	,,	14·89	41·01	25·75	70·93	0·340	4·39	0·3196	4″ = 9·7	11·9
			2·00						0·820 ×	2·40		20·0	
695	V, 0·61; C, 0·18; Mn, 0·43; no Ni	1 × 0·375	4·00	0·375	15·70	41·87	20·44	54·52	0·300	4·60	0·2460	4″ = 15·0	34·4

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J. O. ARNOLD.

THIRD REPORT.

University College, Sheffield,
June 7th, 1902.

A. F. WIENER, Esq.,
Vanadium Alloys, Ltd.,
31 Lombard Street, London, E.C.

Dear Sir,—With reference to my research on the effect of vanadium when used in structural steel in conjunction with other alloying elements, I have obtained the following results:—

A series of crucible ingots were melted and put down into bars in the manner described in my previous reports. The chemical and mechanical results are set forth in the accompanying table.

Thus 1 per cent. of tungsten raised the elastic limit 5 tons and the stress 14 tons. But 1 per cent. tungsten and 0·25 per cent. vanadium raised the elastic limit 18 tons and the stress nearly 30 tons. The 0·25 vanadium has lifted the elastic limit of the nickel steel about 13 tons and the stress about 12 tons. A 50-ton steel with 28 per cent. elongation is excellent.

The vanadium has lifted the chrome steel elastic limit over 13 tons and the stress about 14 tons. This 55-ton steel, with 26 per cent. of elongation, is a very remarkable material.—I remain, dear Sir, yours faithfully,

J. O. ARNOLD,
Professor of Metallurgy.

Table showing Effect of Vanadium when used with other Alloying Elements.

Approximate Chemical Compositions.	Elastic Limit, Tons per Square Inch.	Maximum Stress, Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.
Standard plain steel carbon, 0·25 per cent.	18·0	27·0	38·0	65·0
Carbon . . . 0·25 per cent. Tungsten . . 1·0 ,, Manganese . . 0·4 ,,	23·89	40·83	33·5	45·7
Carbon . . . 0·25 ,, Tungsten . . 1·0 ,, Manganese . . 0·4 ,, Vanadium . . 0·25 ,,	35·61	56·27	15·5	20·9
Carbon . . . 0·25 ,, Nickel . . . 1·0 ,, Manganese . . 0·4 ,,	24·94	37·58	39·5	46·1
Carbon [1] . . 0·25 ,, Nickel . . . 1·0 ,, Manganese . . 0·4 ,, Vanadium . . 0·25 ,,	37·62	49·26	28·0	32·0
Carbon . . . 0·25 ,, Chromium . . 1·0 ,, Manganese . . 0·4 ,,	26·48	41·15	35·5	55·2
Carbon [2] . . 0·25 ,, Chromium . . 1·0 ,, Manganese . . 0·4 ,, Vanadium . . 0·25 ,,	39·76	55·08	26·0	53·0

[1] Ingot No. 741.

[2] Ingot No. 742.

J. O. ARNOLD.

OBITUARY.

William Evans, Vice-President of the Iron and Steel Institute, died, after a short illness of two days' duration, at his residence at Merthyr on February 12, 1915, at the age of seventy-two, having been born at Abergwesyn, Brecknockshire, in 1843. At an early age he commenced work at the Dowlais Ironworks, where he became furnace manager at the age of twenty-eight. He subsequently occupied a similar position at the works of the Rhymney Company, Limited, at Cardiff, and was for a short time works manager of the Erimus Works at Stockton-on-Tees. Returning to South Wales, he was appointed General Manager of the Cyfarthfa Iron and Steel Works and Collieries, in which capacity he remained with the firm until its amalgamation with Messrs. Guest, Keen & Nettlefolds, when he became general manager of all the works and collieries of that company in South Wales. He displayed keen interest in the South Wales coal trade, was a constant attendant of the meetings of the Conciliation Board, and was for some time chairman of the Monmouthshire and South Wales Coal Owners' Association.

He was a member of the Institution of Civil Engineers, and was elected a member of the Iron and Steel Institute in 1882, and a Member of Council in 1894. He was elected a Vice-President of the Institute in 1910.

Arthur Keen, Vice-President of the Iron and Steel Institute, died at his residence at Edgbaston, Birmingham, on February 8, 1915. He was born on January 23, 1835, and, after a comparatively brief schooling, he commenced his business career in the service of the London and North-Western Railway Company at Crewe. His energy in the service of the company led to his appointment as goods agent at Smethwick, where he resided for some years, and where he married the daughter of a wealthy iron-founder, Mr. Astbury. Soon after his marriage, and with his father-in-law's assistance, he entered into partnership with Mr. Watkins, who held the British rights of an American patent for the manufacture of nuts and bolts, which constituted a considerable improvement upon the practice at that time prevailing. In partnership with Mr. Watkins, a small works was started in Smethwick. In 1864 Mr. Keen was able to purchase his partner's interest, and continued the management of the undertaking. Subsequently it was converted into the Patent Nut and Bolt Company, with which was amalgamated an older business, that of the then well-known firm of Weston & Grice. The capital of the new company was £400,000, and the London Works, Smethwick, where the business was carried on, were considerably enlarged. On the death of

Sir Joseph Weston, Mr. Keen was appointed chairman of the company, and by 1885 the success of the concern had been such as to embolden Mr. Keen to acquire other undertakings. In 1900 he purchased the works of the Dowlais Iron Company, and negotiations having been entered into with Guest & Company, iron and steel manufacturers and colliery proprietors, a new company amalgamating the three existing concerns, and with a capital of £2,000,000, was formed. Of this new firm, Guest, Keen & Company, Mr. Keen became chairman and managing director, the other managing directors being the late Mr. E. P. Martin and Messrs. A. T. and F. W. Keen. The success of the new enterprise may be gauged from the fact that at the first annual meeting of the company a net profit of £387,000 was declared. Two years later the business of Crawshay Brothers, Limited, iron and steel manufacturers and colliery proprietors, Cyfarthfa, was bought by the company, together with the screw manufacturing business of Nettlefolds, Limited, the combined undertakings being fused into a new Company, under the name of Guest, Keen & Nettlefolds, Limited, with a capital of £3,000,000. Mr. Arthur Keen was again chairman, and the managing directors were Messrs. E. Nettlefolds, A. T. Keen, F. W. Keen, Charles Steer and Edward Steer.

Simultaneously with the conduct of these enterprises Mr. Keen became a director of the Birmingham and Midland Bank, the large local business of which Mr. Keen decided to extend by allying it with the Sheffield Union Bank and the Yorkshire Banking Company. In 1891 the concern was converted into the London and Midland Bank, and in 1898 it was amalgamated with the City Bank, under the title of the London, City and Midland Bank. He resigned his chairmanship at the beginning of 1908.

In addition to the undertakings in the creation of which he was more directly concerned, he was for some time chairman of the Muntz Metal Company, chairman of the New Cransley Iron and Steel Company, Limited, and a director of Messrs. Bolckow, Vaughan & Company, Limited, and of the Loddington Ironstone Company, Limited. He also found time to devote much of his leisure to public work, and was for twenty-five years a member of the old Local Board at Smethwick, during fifteen years of which he acted as chairman. The growth of Smethwick during this period was largely due to Mr. Keen's connection with the town. New public buildings were erected, municipal gas supplies provided, parks laid out, and baths and free libraries built. His benefactions were not, however, confined to Smethwick, and he was a generous supporter of the Birmingham University, of which he was a Life Governor.

In politics he was a Liberal-Unionist and a strong supporter of Tariff Reform, but, although many opportunities were afforded him of entering Parliament, he always declined to do so on the score of his numerous business engagements. He took a deep interest in labour questions, and was for many years a member of the Midland Iron and Steel Wages Board.

He was a Vice-President of the Institution of Mechanical Engineers, but resigned that office in 1911. He was elected a member of the Iron and Steel Institute in 1885, and in 1891 became a Member of Council. In 1895, on the occasion of the visit of the Institute to Birmingham, he was a member of the Local Reception Committee, and contributed largely to the success of the meeting. It was in this year that he was elected a Vice-President, an office he retained to the time of his death.

William Edgar Allen died on Thursday, January 28, 1915, at his residence, Whirlow House, on the outskirts of Sheffield, at the age of seventy-seven. His earlier education was carried out at home and was completed at Paris, after which he visited, and for some time resided in, Holland, Germany, Spain, Portugal and Italy. During this period of his career he became an accomplished linguist, and also availed himself of the facilities at his disposal to acquire an insight into the requirements of the markets of those countries, with the result that upon his return to Sheffield he determined to devote himself to supplying those demands. The firm of Edgar Allen & Co., Ltd., which is known as the Imperial Steel Works, was established in 1868 and reconstructed in 1903, when the business of Messrs. Askham Brothers & Co., Ltd., and the Yorkshire Steel & Engineering Works, Limited, were taken over. When the firm was converted into a limited liability company the first colleagues of Mr. Allen on the Board were Mr. R. Woodward, Mr. A. E. Wells, and Mr. F. A. Warlow. The Company was registered in 1901, with an authorised capital of £525,000.

Owing to the state of his health he had to spend much of his time abroad, but, although unable, from this cause, to take an active part in the public life of Sheffield, he was a generous patron of the city, to which he made many benefactions. He founded the Edgar Allen Institute for Medico-mechanical Treatment and built and endowed the Edgar Allen Library of the Sheffield University, to which he gave £10,000. The University conferred upon him, as a mark of the esteem in which he was held, the honorary degree of Doctor of Letters. He was one of the oldest Freemen of the Cutlers' Company, and was an Associate Member of the Institution of Mechanical Engineers. He was elected a member of the Iron and Steel Institute in 1900, and was a constant attendant both at its meetings in London and at its visits abroad.

Thomas Abraham Bayliss died on April 21, 1915, at the age of fifty-three. He was the chairman and managing director of the King's Norton Metal Company, Birmingham, which, in conjunction with his father, the late Mr. T. R. Bayliss, he founded in 1889. The father and son together perfected a machine designed to improve the methods of casting, rolling, and general working of metals for ammunition, and they manufactured the first six-pounder case for the Nordenfeldt gun, which was adopted by the Government. He took a keen interest in local affairs, and sat on various councils and committees in Birmingham and Worcestershire. Throughout his public career he displayed considerable ability, and studied the interests of the community with that care which had always characterised him in his private affairs and business.

He was elected a member of the Iron and Steel Institute in 1896, and was a frequent attendant at its meetings both at home and abroad.

Robert James Caldwell died on April 4, 1915, in his thirty-second year. He gave early promise of a brilliant scholastic career, gaining at the Aske Haberdashers' School, London, a series of distinctions, including the Junior and the Senior Scholarships of the London County Council and the Clothworkers' Exhibition. Later he went through the London Chamber of Commerce Examinations with honours, and gained the Princess Louise Prize. He continued his studies at the Central Technical Institute, and took the degrees of B.A. and D.Sc. of the London University.

For two years he filled the position of Instructor and Lecturer in Chemistry at the Central Technical Institute. Following this he was appointed consulting chemist to Messrs. Harland & Wolff, Ltd., at Southampton, and in 1913 he was transferred to Belfast as head of the testing department and consulting chemist.

He was elected a member of the Iron and Steel Institute in 1914.

Joseph Cook died at his residence, Cumberland House, Harrogate, on March 11, 1915, aged sixty-five. He led a very active business life up to within a few days of his death, and was managing director of Joseph Cook, Sons & Co., Washington Ironworks, County Durham. For many years he held a commission in the 4th Volunteer Battalion of the Durham Light Infantry, retiring with the rank of Lieutenant-Colonel, and receiving the Volunteer Officers' Decoration.

He was elected a member of the Iron and Steel Institute in 1879.

Second-Lieutenant **Erasmus Darwin**, of the 4th Battalion Alexandra, Princess of Wales's Own Yorkshire Regiment, was killed in action near Ypres on April 23, 1915. He was the only son of Horace Darwin, M.A., F.R.S., of The Orchard, Cambridge, who himself was a younger son of Charles Darwin. Erasmus Darwin was born on December 7, 1880, and was educated at Marlborough, where he gained an exhibition for mathematics at Trinity College, Cambridge. When at Cambridge, to which he subsequently proceeded, he graduated in the Engineering Tripos in 1905, after which he worked for some time with Messrs. Mather and Platt, Manchester. When the war broke out he occupied an important position with Messrs. Bolckow, Vaughan & Co., Middlesbrough. He was also a director of the Scientific Instrument Company at Cambridge, of which his father was chairman. During his brief career he evinced great administrative ability and judgment, and earned the esteem and affection of those with whom he came in contact. He was elected a member of the Iron and Steel Institute in 1908.

James Duffield, of Tallantire Hall, Cockermouth, died on March 7, 1915, at Rotherham, at the age of eighty. The son of a collier, he started work, at the age of seven, in a Staffordshire coal-pit, and worked regularly in that occupation until he was sixteen years old. He never went to school, and it was not until he reached the age of twenty that he began to educate himself by means of handbooks and attendance at classes. After leaving the pit he found work as under-puddler with a firm in Staffordshire. Two years later he went to the Princes End Works of Barron & Hall, where the manufacture of bar-iron and boiler-plates was carried on. Shortly after, he was engaged at the Parkgate Ironworks at Sheffield, where he developed great skill in puddling iron for armour-plates at the time when the Admiralty were beginning to replace wooden ships by iron vessels. When Cammell, Laird & Co. began to manufacture armour-plate, he secured a position with that company, and puddled the iron for their first armour-plate. Owing to his considerable practical knowledge of metallurgy, he was able to afford invaluable help to Cammell, Laird & Co. in applying commercially the Bessemer process. He had his reward in being appointed manager of the works which the firm built at Dronfield. This position he retained for eleven years. When it became necessary to remove the Dronfield works to the coast, he personally selected the site at Workington, and directed the work of transferring the plant and erecting new furnaces and mills, which now belong to the Workington Iron & Steel Co., Ltd. He was the author of several inventions connected with the manufacture of armour-plate, and when the Admiralty required compound armour, he devised a successful process for combining steel and iron for that purpose. About twelve years ago he resigned the position he had attained as a director of Cammell, Laird & Co., and also the management of their works at Workington, but he still maintained his connection with various manufacturing concerns, and at the time of his death he was the principal shareholder of Moorwoods, Ltd., Harleston Ironworks, Sheffield. He was elected a member of the Iron and Steel Institute in 1891, and was a constant attendant at its meetings for many years.

George James Eveson died at his residence, Shepley Manor, Barnt Green, on June 3, 1915. He was founder and managing director of the G. J. Eveson Coal and Coke Company. He was elected a member of the Iron and Steel Institute in 1896.

Thomas Augustus Griffin died on August 12, 1914. He was born in Rochester, New York, in 1852, and was educated in that city. He subsequently became associated with his father, Thomas F. Griffin, in the foundry business, and in 1870 went to Detroit, where he and his father founded the Griffin Wheel Company of Detroit. A branch was established in Chicago, which later, under his able organisation, was designed to become the principal establishment and the parent of numerous branches in various cities of America. The result of his great business ability and application was the development, in the course of thirty-five years, of the largest car-wheel manufacturing industry in the world.

He was the first President of the Griffin Wheel Company, resigning in 1913 to become chairman of the Board of Directors. At one time he was also President of the Ajax Forge at Chicago, which he organised in 1883. He was elected a member of the Iron and Steel Institute in 1891.

Henry Augustus Guy died at his residence, Valley Field, Grosvenor Road, Scarborough, on May 15, 1915. He was closely associated with the introduction of self-hardening steel in America, and was for over twenty years one of the leading steel experts in Sheffield. He was elected a member of the Iron and Steel Institute in 1890.

Charles William Chipchase Henderson died at The Riding, Hexham, on December 3, 1914, at the age of sixty-six. He was educated at Winchester School, where he distinguished himself in athletics. He was one of the best-known men on the Newcastle Exchange, being very largely interested in both the iron and coal trades. He was chairman of the Consett Iron Company, succeeding the late Sir David Dale in that position. He was also connected with a number of collieries, being managing director of the Bedlington Coal Company, and also director of a number of important undertakings. He was also a director of the Northumberland Coal Owners Association.

He had a long and honourable association with hunting and racing, and was even more widely known in connection with sport than in business. In politics he was a Unionist, and frequently presided at meetings in the Hexham Division, but, though often urged to do so, he always declined to contest the seat himself. For more than twenty years he held a commission in the Northumberland Hussars, retiring with the rank of major in 1896.

He was elected a member of the Iron and Steel Institute in 1895.

Daniel Jones Hirst died on May 15, 1915, at Barrow-in-Furness. Upon leaving school he entered the Dowlais Ironworks, of which his father, the late Mr. Thomas Hirst, was mill manager. For the past twelve years he had been associated with the Barrow Hematite Steel Co., Ltd. He was elected a member of the Iron and Steel Institute in 1886.

Arthur Cameron Hurtzig died on June 26, 1915. He was born in 1853, and was the son of the late Charles Hurtzig. He received his preliminary education at Ware Grammar School, and afterwards at University College, London, where he gained a diploma in engineering. After serving for three years with the late Sir Benjamin Baker, he became, in 1875, principal assistant to Mr. T. R. Winder, the resident engineer on the Rosslare harbour and Waterford and Wexford railway works. A few years later he became engaged on the new dock works and graving docks at Hull. From January 1881 to July 1885 he had charge, as resident engineer, of the Alexandra Dock works of the Hull, Barnsley, and West Junction Railway and Dock Company, and in the latter year he became chief engineer, retaining that post for three years. In 1888 he left Hull in order to become chief assistant to Sir John Fowler and Sir Benjamin Baker, and thereafter took his part in all the important works carried out by that firm, into which he was taken as junior partner in 1891. In 1898, on the death of Sir John Fowler, the firm became Baker & Hurtzig, and on the death of Sir Benjamin Baker he became the head of the firm. He completed Sir Benjamin Baker's work for the Egyptian Government in respect of the raising of the Assuan Dam and the building of the Isna Barrage. He occupied numerous positions, including those of engineer of the Forth Bridge Railway Company; consulting engineer to the Dover Harbour Board for new works (completed in 1913); joint consulting engineer to the Bristol Corporation in respect of the Avonmouth Dock works; and consulting engineer to the firm of Vickers, Ltd., on several important works, including a shipbuilding and repairing yard and floating dock at Montreal. He acted also as sole arbitrator in many cases affecting the War Office, the London County Council, and other bodies.

He was a member of the Institution of Civil Engineers, and was a frequent contributor to the proceedings of that body and of other technical societies. He was elected a member of the Iron and Steel Institute in 1902.

Major **Walter Johnson**, of Arncliffe Hall, Northallerton, died suddenly on the morning of Tuesday, February 9, 1915, at the residence of his son-in-law, Mr. H. Dickson, at Redcar. He was born in 1842 at West Wickham, in Buckinghamshire, and was the son of the late Rev. W. R. Johnson. He was educated at Rugby and Trinity College. The early part of his life he devoted to a military career, and obtained a commission in the Royal Scots Greys. In 1871 he married Margaret Florence, the daughter of the late Sir Lowthian Bell, Bart. He retired from the Army with the rank of Captain, and, after residing for a time in Wales, commenced business in Middlesbrough as an iron merchant. Some years later he joined the Board of Messrs. Bell, Bros., with which firm he was associated for nearly forty years. He was also a director of Messrs. Dorman, Long & Co., Ltd. He was for many years chairman of the Middlesbrough

Chamber of Commerce, and was a warm supporter of the volunteer movement, having been for some time in command of the two Middlesbrough Companies of the Durham Light Infantry, from which he retired with the rank of Major. He was elected a member of the Iron and Steel Institute in 1907.

Henry Jonas died on April 6, 1915, at the age of thirty. He was the fourth son of Sir Joseph Jonas, and a director of Sir Joseph Jonas, Colver & Co., Ltd., steel manufacturers, of Sheffield. He was educated in Sheffield and Scarborough, and afterwards travelled in France, Belgium, Holland and Spain. He was in America on the business of his company when he contracted pneumonia, from which he died. He was elected a member of the Iron and Steel Institute in 1911.

Archibald Simpson Keith died at his residence, Parkhurst, Chapeltown Road, Leeds, on January 3, 1915. He was born at Normanby, near Middlesbrough, in 1856, and was the second son of Dr. Alexander Keith. After being educated privately, he entered the office of Mr. A. C. Downey, who was then superintending the erection of the Coatham Iron Works. He subsequently entered the service of the Loftus Iron Company (now the Skinningrove Iron Company) as assistant draughtsman. After a further experience in the drawing-office of Messrs. Westry, Copeland, marine engineers of Barrow, he was appointed assistant works manager at the Normanby Iron Works, Middlesbrough, which position he held for twenty years. He then superintended, under Mr. Tom Westgarth, the re-organisation and rebuilding of the engineering shops of Messrs. Furness, Westgarth & Co., and put down some very heavy modern plant for marine boiler construction.

In 1897 he was appointed blast-furnace manager to Walter Scott, Ltd., Leeds Steel Works, subsequently becoming assistant works manager, and on the death of Mr. E. Richards in 1910 became general works manager, which position he held at the time of his death. He had a wide knowledge of engineering, which he successfully applied to the manufacture of iron and steel. During his connection with the Leeds Steel Works, many additions of plant and machinery were made. He was a member of the Engineering Standards Committee on rails, tram-rails, and sections; of the Cleveland Institution of Engineers, and of the Leeds Association of Engineers.

He was elected a member of the Iron and Steel Institute in 1910.

Sir Arthur Tredgold Lawson, Bart., of Bedale Hall, Yorkshire, died at his London residence, 68 Eaton Square, on June 2, 1915, aged seventy-one. He was born on February 8, 1844, and was a son of Mr. John Lawson, of Bramhope Manor, near Leeds. He was chairman of the firm of Fairbairn, Lawson, Combe, Barbour, Ltd., of Leeds, and a director of the Great Eastern Railway. He was created a baronet in 1900, and was a Chevalier of the Legion of Honour.

He was elected a member of the Iron and Steel Institute in 1876.

John Henry Lloyd died on April 16, 1915. He was born at Dowlais in 1859, and was educated at the Dowlais public schools and at Lloyd's School, Merthyr Tydfil. In 1874 he entered the machine shop of the Dowlais Iron Company, and served an apprenticeship there of five years. He then spent a year as machinist at the Tredegar Iron Works, and in 1880 he returned to Dowlais as machinist, and remained in the employ of that company until his departure for the United States.

He went to Alliance, Ohio, in 1882, and secured a position with his uncle, the late Thomas R. Morgan, senior, in the engineering department of Morgan, Williams & Company, now the Morgan Engineering Company, where he was employed successively as draftsman, mechanical engineer, general superintendent, and finally as assistant to the president of the company. On account of ill-health he retired from active participation in the business about a year and a half ago.

He was elected a member of the Iron and Steel Institute in 1905.

Erik Johann Ljungberg, Hon. Vice-President of the Iron and Steel Institute, died on April 5, 1915, at Stockholm, at the age of seventy-two. He was born on March 4, 1843, at Hammarn, in Grythytlepain, in the province of Orebro. His family were closely connected with mining; he grew up in a mining district, and entered early upon the career in which he was destined to attain such a prominent position. Having passed through the Filipstad Mining College, he held several posts, until, in 1875, he was called to take over the management of Stora Kopparbergs Bergslag, one of the largest industrial concerns in Sweden, of which he became the managing director when it was transformed into a limited company. He retired on June 14, 1913, with the most ample recognition of his excellent services.

Mr. Ljungberg's connection with the Stora Kopparbergs Bergslag was marked by the continuous enterprise and expansion of the Domnarfvet Iron Works, which under his management has become one of the most famous in the world. The Skutskär saw-mills also owed their existence to his initiative, as well as the sulphite factory and the Kvarnsveden paper-mills, the rolling-mills at Domnarfvet, and the Bullerfors and Mockfjord hydro-electric power-stations.

He was in many respects the pioneer of Sweden's iron and other industries, and was the first to take in hand the experiments in electric iron-ore smelting, which were carried on at Domnarfvet, where this process is now being installed on a large scale. He also took the lead in the matter of utilising the residues from the sulphite manufactures, and he was also much interested in the problem of using sulphite spirit for motor purposes. The Ljungberg charcoal furnace was another outcome of his initiative, its purpose being the utilisation of auxiliary products.

He was also President of the Industrial Union of Sweden and Vice-President of the Swedish Waterfalls Union.

On the occasion of his retirement, the Stora Kopparbergs Company presented him with an address of thanks, encased in a casket of gold from the company's mines, in which, amongst other things, it was pointed out that the turnover then was six times what it had been when he joined it, and that the net profits during the same time had increased fourteen-fold. The company on the same occasion formed a fund of £11,000, the interest of which, according to Dr. Ljungberg's wish, is to be applied to the advancement of the sale of mining products abroad through the instrumentality of the company's workmen, foremen, and officials.

He was a model employer. He took great care of his workpeople in every way, and instituted for them good housing accommodation, practical schooling for the children, and housewifery for their wives and daughters. It was owing to his interest and generosity that the Falun Mining College became possessed of a handsome new building. He also gave large sums to national and high schools of the district.

Many distinctions were conferred upon him. He was a member both of the Swedish Academy of Science and of the Academy of Agriculture; he held the great gold medal of Jernkontoret, and in 1909 received the degree of Honorary Doctor of Philosophy of the Stockholm University. He was a Grand Commander of the Order of Vasa, and was elected a member of the Iron and Steel Institute in 1880, and an Honorary Vice-President in 1909. He was a frequent attendant at the meetings of the Institute, and in August 1898, when the Autumn Meeting of the Iron and Steel Institute was held in Stockholm, Mr. Ljungberg, who occupied a prominent position in the reception committee, welcomed the members to Falun and personally conducted them over the company's works and mines.

MAURICE MAGERY, of Villa St. Pierre, Namur-la-Plante, Belgium, died on October 9, 1914. He was the son of the late Jules Magery, at one time manager of the Rothe Erde works near Aix-la-Chapelle, Germany, and of the Tilleul rolling-mills near Maubeuge. Like his father, he commenced his professional career as a mining engineer, and was a member of the Société de l'Industrie Minerale and of the Association des Ingénieurs sortis de l'Ecole de Liège, where his technical training had been acquired. On the occasion of the visit of the Iron and Steel Institute to America in 1904, he collaborated with Mr. Timmermans, Mr. Dreux, and his father in publishing an exhaustive account, in French, of the principal works visited. He was a frequent attendant at meetings of the Institute, of which he was elected a member in 1890.

WILLIAM MITFORD died at Coatham, Redcar, on February 17, 1915, in his eighty-fourth year. Prior to his retirement a few years ago, he was for many years inspector of rails for the North-Eastern Railway Company.

He was elected a member of the Iron and Steel Institute in 1894.

John Parry died on December 2, 1914, at his residence at Forest Hill, London, at an advanced age. In his earlier years he was employed as a chemist under his father, the late Charles Parry, a metallurgical engineer of note and a prolific inventor. Young Parry was associated, together with his father, in the experiments made in the early days of the basic process by Thomas and Gilchrist. He read many papers before the Institute, and was a frequent attendant at meetings. He was an original member of the Institute.

James Cartmell Ridley died on December 27, 1914. He was apprenticed to Robert Stephenson & Co., locomotive engineers, and then served for a short time as engineer on one of the Tyne steamers. He then accepted the management of the Wallsend Blast-Furnaces and Coke-Ovens, where he remained until they were sold to the Greek Iron Company, and then became manager of the Jarrow Rolling-mills. In 1871 he patented a new process for the manufacture of iron and steel. When the Jarrow Works became a limited liability company, he formed the firm of Bell, Ridley, and Bell, and took over the Walker Iron Works, Newcastle-on-Tyne. He afterwards started the Swalwell Steel Works, under the name of Ridley & Co.

He was an original member of the Iron and Steel Institute.

Captain William E. Rogerson, of Neasham Abbey, Darlington, Adjutant of the 12th Service Battalion Durham Light Infantry, died suddenly, from heart failure, at Bullswater Camp, near Woking, on Friday, November 13, 1914. He was born in 1872, and was a son of the late Mr. John Rogerson of Croxdale Hall, Durham. He was elected a member of the Iron and Steel Institute in 1890.

Robert Schott died at Harlow Heath, Harrogate, on February 3, 1915, aged seventy-four. He was formerly in partnership with the late Mr. Henry Seebohm as manufacturers of crucible steel at Dannemora Steelworks, Sheffield. On the conversion of the firm into a limited company he became managing director, but shortly afterwards retired from the position.

He became a member of the Iron and Steel Institute in 1881.

William Thackray died on March 8, 1915, at Sunderland at the age of seventy. He was managing director of Samuel Tyzack & Co., Ltd., of Sunderland. He held a prominent position among the ironmasters of the north-east district; he was Chairman of the North of England Iron and Steel Conciliation Board, and a member of the River Wear Commission. He was elected a member of the Iron and Steel Institute in 1885.

Carl Gustav Wahlberg, of Bofors, Sweden, died on February 16, 1914. He was born at Stockholm in 1870, and graduated at the Royal Naval College in 1891 and at the Academy of Artillery and Military Engineering in 1898. He held the position of Controller to the Navy at Bofors from 1898 to 1901, but vacated it to take up a post at the Bofors Works, where, in 1904, he became Director of Artillery and at the same time general superintendent of the whole plant, a position he occupied at the time of his death. He had a very high reputation both as a naval officer and as an expert on guns both for the Navy and the Artillery. He was a member of the Association of Swedish Naval Officers, and was elected a member of the Iron and Steel Institute in 1905.

John Pears Walton died at High House, Acomb, near Hexham, in April 1915, at the age of seventy-seven. He was connected for nearly half a century with the Fallowfield lead and coal mines. He was elected a member of the Iron and Steel Institute in 1875.

Adolph Swain While died at Hughesovka, Russia, on November 21, 1914. He was born at Rhymney in 1850, and passed his early youth in practical training in South Wales. As a young man he went to Russia, where he resided for nearly forty years, during a period which was practically correlative with that of the development of the iron and steel industry of that country, then in its infancy. He spent ten years in the interior of Russia, at Briansk, in the government of Kaluga, and at Nijni-Novgorod.

It was, however, chiefly in connection with the development of the New Russia Company that his activities were exercised, and at these works he had the experience of rolling the first rails made in the Empire from Russian ore. The latter twenty years of his life were spent at the works, which have become the centre of the rapidly developed metallurgical district of the Donetz basin. He was elected a member of the Iron and Steel Institute in 1883.

Stuart Wood died on March 2, 1914, at his residence, 1620 Locust Street, Philadelphia, U.S.A. He was born in that town in 1853, was educated at Haverford College and Harvard University, and later took a special course in philosophy at a college in Germany. He received the degree A.B. from Haverford in 1870, and the degree of Ph.D. from Harvard in 1875. At the age of twenty-four he entered the employ of R. D. Wood & Co., engineers, which was founded by his father, and of which his brother, Mr. Walter Wood, eventually became senior partner. He was president and treasurer of the Tampa Water Works, Florida, and a director of the Florence Iron Works and the Camden Iron Works, New Jersey. He was a member of the American Institute of Mining Engineers, American Gas Institute, American Academy of Social and Political Science, American Philosophical

Society, and several English and French Societies of Political Economy and Social Science.

He was elected a member of the Iron and Steel Institute in 1889.

The Council have also to note with regret the death of Mr. **Pierre Blaise Emile Martin**, Knight of the Legion of Honour and Bessemer Medallist, which occurred on May 23, 1915, at his residence at Fourchambault, at the advanced age of ninety-one. Although he was not a member of the Institute, he had had so distinguished a career as a metallurgist that it is felt that official note should be taken of his death.

Pierre Martin was born at Bourges, France, on August 18, 1824, and was the son of Mr. Emile Martin, the owner of the Sireuil Ironworks, Charente. Although the process with which his name is connected enjoys world-wide celebrity, the inventor himself was practically forgotten until towards the end of 1909, when he was ascertained to be living in very straitened circumstances near Nevers. As soon as the fact became known, the Comité des Forges de France decided to institute a fund in order to afford some reparation to the aged metallurgist for the disappointments and hardships he had undergone, and headed the list with £4000. The German Ironmasters' Association, Great Britain, Belgium, Italy, Austria-Hungary, and other steel-making countries also contributed. In this country the initiative was taken by the Iron and Steel Institute, and the committee formed included the Duke of Devonshire, Sir Hugh Bell, Mr. C. J. Bagley, Mr. W. Beardmore, Mr. Illtyd Williams, Mr. G. Hatton, and Mr. M. Mannaberg.

At the presentation ceremony, Mr. C. P. E. Schneider of the Creusot Works, vice-president of the Comité des Forges, presided, and among those present were M. Millerand, Minister of Public Works, who attended on behalf of the French Government, Professor Le Chatelier, Mr. G. C. Lloyd, Dr. Schrödter, and Mr. Greiner.

Further particulars of the career of Mr. Pierre Martin will be found in the speech made by Mr. Cooper, Acting President of the Institute on the occasion of the presentation of the Bessemer Medal at the May meeting, which appears on pp. 25–27 of the present volume.

David Alexander Louis, who, although not a member, was for many years intimately connected with the Institute, died on March 25 after a long illness. He was born in 1857, and his scientific training was acquired at the Royal School of Mines. He contributed a number of papers to the *Transactions of the Chemical Society*, the *Philosophical Transactions of the Royal Society* and to the *Proceedings of the Institute of Mining and Metallurgy*, the Petroleum Institute, and the Iron and Steel Institute, and enjoyed the warm esteem of those who knew him as a mining engineer of wide experience. Among the offices that he filled were Professor of Mining at the Yorkshire College, Leeds—now the University of Leeds, and Lecturer on Mining at the Crystal Palace School of Practical Engineering. In 1910 he acted as Honorary Secretary of the Metallurgical Section of the Seventh International Congress of Applied Chemistry, and he was an active member of the International Association of Journalists, in connection with which he acted on various reception committees from time to time. He had a wide connection with the technical press, and took great interest in the meetings of the technical societies. He was an almost invariable attendant at the meetings of the Institute, both at home and abroad.

ADDITIONS TO THE LIBRARY

DURING THE FIRST HALF OF 1915.

Title.	By whom Presented.
American Iron and Steel Institute: Year Book 1915. Compiled by James T. McCleary. Large 8vo. New York, 1914.	American Iron and Steel Institute.
Annual Tables of Constants and Numerical Data: "Données Numériques de Cristallographie et de Minéralogie" par L. J. Spencer. Préface de A. Lacroix. Extrait du Vol. iii. Année 1912. 4to. Paris and Chicago, 1914.	Gauthier-Villars et Cie.
Arnold, J. O: "British and German Steel Metallurgy." (Oxford Pamphlets, 1914–1915.) 8vo. London, 1915.	The Author.
Arnold, J. O., and A. A. Read: "The Chemical and Mechanical Relations of Iron, Cobalt, and Carbon." (The Institution of Mechanical Engineers.) 8vo. London, 1915.	J. O. Arnold.
Brearley, Harry: "The Case-Hardening of Steel." 8vo. London, 1914.	Messrs. Iliffe & Sons, Limited.
British Columbia Bureau of Mines: Bulletin No. 2, 1914: "The Mineral Resources of the Lardeau and Trout Lake Mining Divisions." By Newton W. Emmens. Large 8vo. Victoria, B.C., 1914.	Minister of Mines.
Canada, Commission of Conservation: "Forest Protection in Canada, 1912." By Clyde Leavitt. (Committee on Forests.) Large 8vo. Toronto, 1913.	The Commission.
Canada, Commission of Conservation: Trent Watershed Survey. A Reconnaissance by C. D. Howe and J. H. White. With an Introductory Discussion by B. E. Fernow. (Committee on Forests.) Large 8vo. Toronto, 1913.	
Canada, Commission of Conservation: "Forest Conditions of Nova Scotia." By B. E. Fernow, assisted by C. D. Howe and J. H. White. Large 8vo. Ottawa, 1912.	
Canada, Commission of Conservation: "Mine-Rescue Work in Canada." By W. J. Dick. (Committee on Minerals.) Large 8vo. Ottawa, 1912.	
Canada, Commission of Conservation: "Conservation of Coal in Canada, with Notes on the Principal Coal Mines." By W. J Dick. (Committee on Minerals.) Large 8vo. Toronto, 1914.	
Canada, Commission of Conservation: "Long Sault Rapids, St. Lawrence River. An Enquiry into the Constitutional and Other Aspects of the Project to Develop Power Therefrom." By Arthur V. White. (Committee on Waters and Water-Powers.) Large 8vo. Ottawa, 1913.	
Canada, Commission of Conservation: "Water-Powers of Canada." By Leo. G. Denis and Arthur V. White. [With map.] Large 8vo. Ottawa, 1911.	
Canada, Commission of Conservation: Third, Fourth, and Fifth Annual Reports. Large 8vo. Montreal, 1912–14.	
Canada, Commission of Conservation: "Report on Lands, Fisheries and Game, and Minerals" for the Year 1911. Large 8vo. Ottawa, 1911.	

Title.	By whom Presented.
Canada, Department of Mines, Mines Branch: "Summary Report for the Calendar Year ending December 31, 1913. Large 8vo. Ottawa, 1914.	The Director.
Canada, Department of Mines, Mines Branch: "Annual Report on the Mineral Production of Canada during the Calendar Year 1913." Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: "Economic Minerals, and Mining Industries of Canada." Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: "Moose Mountain Iron-Bearing District, Ontario." By E. Lindeman. [With maps.] Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: "Preliminary Report on the Bituminous Sands of Northern Alberta." By S. C. Ells. Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: Bulletin No. 9: "Investigation of the Peat Bogs and Peat Industry of Canada, 1911–12." By A. v. Anrep. Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: Bulletin No. 10: "Notes on Clay Deposits near McMurray, Alberta." By Sydney C. Ells. Large 8vo. Ottawa, 1915.	
Canada, Department of Mines, Mines Branch: Report No. 203: "Report on the Building and Ornamental Stones of Canada." Vol. ii. Maritime Provinces. By Wm. A. Parks. Large 8vo. Ottawa, 1914.	
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Canada, Department of Mines, Mines Branch: Report 245: "Gypsum in Canada. Its Occurrence, Exploitation, and Technology." By L. H. Cole. Large 8vo. Ottawa, 1913.	
Canada, Department of Mines, Mines Branch: Report 254: "Magnetite Occurrences near Calabogie, Renfrew County, Ontario." By E. Lindeman. Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: Report 279: "Report on the Building and Ornamental Stones of Canada." Vol. iii. Province of Quebec. By Wm. A. Parks. Large 8vo. Ottawa, 1914.	
Canada, Department of Mines, Mines Branch: Report No. 299: "Peat, Lignite, and Coal. Their Value as Fuels for the Production of Gas and Power in the By-Product Recovery Producer." By B. F. Haanel. Large 8vo. Ottawa, 1914.	
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Title.	By whom Presented.
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Canada, Department of Mines, Mines Branch: Report No. 383: "Preliminary Report. The Mineral Production of Canada during the Calendar Year 1914." Prepared by John McLeish. Large 8vo. Ottawa, 1915.	
Canada, Geological Survey: "Summary Report of the Geological Survey for the Calendar Year 1913." Large 8vo. Ottawa, 1914.	The Director.
Canada, Geological Survey: Memoir No. 30: "The Basins of Nelson and Churchill Rivers." By William McInnes. Large 8vo. Ottawa, 1913.	
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Canada, Geological Survey: Memoir 61, Geological Series No. 45: "Moose Mountain District, Southern Alberta." Second Edition. By D. D. Cairnes. Large 8vo. Ottawa, 1914.	
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Cavallier, Camille: "La France Exportatrice et l'Allemagne Exportatrice." (Commerce Extérieur de la France.) Large 8vo. Paris, 1915.	The Author.
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Galloway, W.: "Great Colliery Explosions, and their Means of Prevention." 8vo. London, 1914.	The Author.
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Illinois University, Engineering Experiment Station: Bulletin No. 77: The Effect of Boron upon the Magnetic and other Properties of Electrolytic Iron melted *in vacuo*." By Frygve D. Yensen. 8vo. Urbana, 1915.	Illinois University.
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Master Car Builders' Association: "Report of the Proceedings of the Forty-Eighth Annual Convention, 1914." Vol. XLVIII. In 2 Parts. 8vo. Chicago, 1914.	Master Car Builders' Association.
Museum of Practical Geology: "A Handbook to the Collection of Kaolin, China-Clay, and China-Stone in the Museum of Practical Geology." By J. Allen Howe. With Appendix by Allan B. Dick. Large 8vo. London, 1914.	Museum of Practical Geology.
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Patent Office, London: "Key to the Classifications of the Patent Specifications of France, Germany, Austria, Netherlands, Norway, Denmark, Sweden, and Switzerland in the Library of the Patent Office." Third edition. 12mo. London, 1915.	Patent Office.
Pavloff, M. A: "Calculation of Blast Furnace Charges." [In Russian.] Large 8vo. Petrograd, 1914.	The Author.
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Royal Society: "Year Book, 1915." 8vo. London, 1915.	Royal Society.
Scotland Geological Survey: Memoirs 110 and 116: "The Geology of Caithness." By C. B. Crampton and R. G. Carruthers. Large 8vo. Edinburgh, 1914.	The Director.
Scotland: Memoirs of the Geological Survey: "The Geology of Mid-Strathspey and Strathdearn." By L. W. Hinxman and E. M. Anderson. Large 8vo. Edinburgh, 1915.	
Scotland: Memoirs of the Geological Survey: "The Geology of the Country round Beauly and Inverness; including a part of the Black Isle." By J. Horne and L. W. Hinxman, with Contributions by B. N. Peach and E. H. Cunningham Craig, and Petrographical Notes by J. S. Flett. Large 8vo. Edinburgh, 1914.	
Smith, E. W. Fraser: "The Future of British Engineering and Shipbuilding." (North-East Coast Institution of Engineers and Shipbuilders.) Large 8vo. Newcastle-on-Tyne, 1915.	The Author.
"Spon's Architect's and Builder's Pocket Price Book, 1915." Edited by Clyde Young and Stanford M. Brooks. Forty-second edition. 12mo. London, 1915.	E. & F. N. Spon, Limited.
Sweden, Board of Trade: "Bergshantering berättelse för år, 1913," av Kommerskollegium. (Sveriges Officiella Statistik.) 8vo. Stockholm, 1914.	Kommerskollegium.
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United States Bureau of Standards: Scientific Paper No. 242: "The Emissivity of Metals and Oxides. II. Measurements with the Micropyrometer." By G. K. Burgess and R. G. Waltenberg. Large 8vo. Washington, 1915.	
United States Geological Survey: "Mineral Resources of the United States, 1912." Part I.—Metals. Part II.—Non-Metals. [In 2 vols.] 8vo. Washington, 1915.	The Director.
Urquhart, James: "The Life and Teaching of William Honyman Gillespie of Torbanehill." With a Biblio-	James Urquhart.

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Victoria Geological Survey: Bulletin No. 34: "Economic Geology and Mineral Resources of Victoria." By H. Herman. Large 8vo. Melbourne, 1914.	The Director.
Victoria Geological Survey: Bulletin No. 35: "The Jubilee Mines, Scarsdale." By W. Baragwanath. Large 8vo. Melbourne, 1914.	
Western Australia Department of Mines: "Report for the Year 1913." Folio. Perth, 1914.	The Director.
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Western Australia Geological Survey: Bulletin No. 57: "A Geological Reconnaissance of a Portion of the Murchison Goldfield." By H. P. Woodward. 8vo. Perth, 1914.	
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Gowland, William: "The Metallurgy of the Non-Ferrous Metals." Large 8vo. London, 1914.

Home Office, London: "Report of the Departmental Committee appointed to inquire into the Conditions prevailing in the Coal Mining Industry due to the War." Part I. Report. Folio. London, 1915.

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Jones, J. H.: "The Tinplate Industry, with Special Reference to its Relation with the Iron and Steel Industries." 8vo. London, 1914.

"Quin's Metal Handbook and Statistics, 1915." Oblong 8vo. London, 1915.

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Wilkinson, John: "John Wilkinson, Ironmaster." By H. W. Dickinson. 8vo. Ulverston, 1914.

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INSTITUTIONS.

The Publications of the Institute are exchanged for those of the following Departments and Institutions:—

London.

Board of Trade.
Chemical Society.
City and Guilds (Engineering) College.
Engineering Standards Committee.
Faraday Society.
Geological Society.
Geological Survey.
Home Office.
Imperial Institute.
Institute of Chemistry.
Institute of Metals.
Institution of Civil Engineers.
Institution of Electrical Engineers.
Institution of Mechanical Engineers.
Institution of Mining and Metallurgy.
Institution of Mining Engineers.
Institution of Naval Architects.
Institution of Petroleum Technologists.
National Physical Laboratory.
Patent Office.
Royal Artillery Institution.
Royal Institute of British Architects.
Royal Institution.
Royal Microscopical Society.
Royal Society.
Royal Society of Arts.
Royal Statistical Society.
Society of Chemical Industry.
Society of Engineers.
Society of Public Analysts.
University College.

Provincial.

Armstrong College, Newcastle-on-Tyne.
Birmingham University.
British Foundrymen's Association.
Cleveland Institution of Engineers.
Edinburgh University.
Institution of Engineers and Shipbuilders in Scotland.
Leeds University, Engineering Society.
Liverpool Engineering Society.
Manchester Association of Engineers.
Manchester Geological and Mining Society.
Mining Institute of Scotland.
Municipal School of Technology, Manchester.
North-East Coast Institution of Engineers and Shipbuilders.
North of England Institute of Mining and Mechanical Engineers.
Royal Dublin Society.
Scotland, Geological Survey.
Sheffield University.
South Staffordshire Ironmasters' Association.
South Wales Institute of Engineers.
Staffordshire Iron and Steel Institute.
University College of South Wales.
West of Scotland Iron and Steel Institute.

British Dominions.

Australasian Association for the Advancement of Science.
Australasian Institute of Mining Engineers.
British Columbia, Minister of Mines.
Canada, Commission of Conservation.
Canada, Department of Mines.
Canada, Geological Survey.
Canadian Mining Institute.
Canadian Society of Civil Engineers.
Geological Survey of India.
Mining Society of Nova Scotia.
Mysore Geological Department.
New South Wales, Department of Mines.
Nova Scotian Institute of Science.
Ontario Bureau of Mines.
Queensland Geological Survey.
Queensland University.
Royal Canadian Institute.
Royal Society of New South Wales.
Union of South Africa, Department of Mines.
Victoria, Department of Mines.
Western Australia, Department of Mines.

United States.

American Foundrymen's Association.
American Institute of Mining Engineers.
American Iron and Steel Institute.
American Society of Civil Engineers.
American Society of Mechanical Engineers.
Engineers' Society of Western Pennsylvania.
Franklin Institute.
Illinois University.
Massachusetts Institute of Technology.
Master Car Builders' Association.
Missouri Bureau of Geology and Mines.
New York Academy of Sciences.
Ordnance Office, War Department, Washington.
Smithsonian Institution.
United States Bureau of Mines.
United States Bureau of Standards.
United States Geological Survey.
Washington Academy of Sciences.

Argentine.

Ministerio de Obras Publicas.

Austria.

*Internationaler Verband für die Materialprüfungen der Technik.
*K. K. geologische Reichsanstalt.
*Oesterr. Ingenieur- und Architekten-Verein.

Belgium.

*Association des Ingénieurs sortis de l'École des Mines de Liége.
*Ministére de l'Intérieur.
*Union des Charbonnages de Liége.

France.

Comité des Forges.
Société d'Encouragement pour l'Industrie Nationale.
Société de l'Industrie Minérale.
Société des Anciens Élèves des Écoles Nationales d'Arts et Métiers.
Société des Ingénieurs Civils.
Société Scientifique Industrielle de Marseille.

Denmark.

Kgl. tekn. Högskolans Materialprofnings anstalt.
Teknisk Bibliotek.

Germany.

*Deutsches Museum.
*Königliche Bergakademie in Freiberg.
*Königliches Materialprüfungsamt.
*Verein deutscher Eisen- und Stahl-Industrieller.
*Verein deutscher Eisenhüttenleute (Journal "Stahl und Eisen").
*Verein deutscher Ingenieure.

Italy.

Associazione fra gli Industriali Metallurgici Italiani (Journal "Metallurgia Italiana").
Collegio degli Ingegneri ed Architetti, Milan.
Collegio Nazionale degli Ingegneri Ferroviari Italiani.
Reale Accademia dei Lincei.

Peru.

"Cuerpo de Ingenieros de Minas."

Sweden.

Commerce-Collegii.
Geological Institution of the University of Upsala.
Jernkontoret.

* Exchange suspended since August 1914.

JOURNALS.

The following periodicals have been presented by their respective Editors:—

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"American Machinist."
"Analyst."
"Automobile Engineer."
"Biggs and Sons' Contractors' Record."
"Cassier's Engineering Monthly."
"Coal and Iron."
"Colliery Guardian."
"Concrete and Constructional Engineering."
"Contract Journal."
"Contractor's Chronicle."
"Electrical Engineering."
"Electrical Review."
"Electrical Times."
"Electrician."
"Engineer."
"Engineer and Iron Trades Advertiser."
"Engineering."
"Engineering Review."
"Hardware Trade Journal."
"Hardwareman."
"Illuminating Engineer."
"Iron and Coal Trades Review."
"Iron and Steel Trades Journal."
"Ironmonger."
"Machinery Market."
"Marine Engineer."
"Mechanical Engineer."
"Mining Magazine."
"Page's Engineering Weekly."
"Petroleum Review."
"Phillips' Monthly Register."
"Practical Engineer."
"Railway News."
"Science Abstracts."
"Science and Art of Mining."
"Shipping World."
"South African Engineering."
"Statist."
"Steamship."
"Syren and Shipping."
"Tramway and Railway World."

British Dominions.

"Canadian Machinery."
"Indian Engineering."
"Indian Textile Journal."

United States.

"American Journal of Science."
"Bradstreets."
"Colliery Engineer."
"Engineering and Mining Journal."
"Engineering Magazine."
"Engineering News."
"Iron Age."
"Iron Trade Review."
"Machinery."
"Metallurgical and Chemical Engineering."
"Mining and Engineering World."
"Steel and Iron."

*Austria.

"Oesterr. Zeitschrift für Berg- und Hüttenwesen."

*Belgium.

"Moniteur des Intérêts Matériels."
"Revue Universelle des Mines."

France.

"Annales des Mines."
"Echo des Mines."
"Fonderie Moderne."
"Génie Civil."
"Mois Scientifique et Industriel."
"Portefeuille Économique."

*Germany.

"Annalen für Gewerbe und Bauwesen."
"Anzeiger fur die Draht-Industrie."
"Eisen-Zeitung."
"Feuerungstechnik."
"Internationale Zeitschrift für Metallographie."
"Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen."
"Jahresbericht des Vereins für die bergbaulichen Interessen in Oberbergamtsbezirk Dortmund."
"Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate."
"Zeitschrift für Elektrochemie."
"Zeitschrift für Praktische Geologie."
"Zeitschrift für Werkzeugmaschinen und Werkzeuge."

Italy.

"Annali di Chimica Applicata."
"Industria."
"Industria Chimica Mineraria e Metallurgica."
"Metallurgia Italiana."
"Rassegna Mineraria."

Spain.

"Ingenieria."
"Revista Minera."

Sweden.

"Svensk Export."
"Teknisk Tidskrift."

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*The presentation of all Austrian, German, and Belgian periodicals has been suspended since August 1914.

The following periodicals have been purchased :—

United Kingdom.

"Chemical News."
"Foundry Trade Journal."
"International Catalogue of Scientific Literature."
"Mining Journal."
"Nature."
"Proceedings of the British Association."
"Reports of the British Fire Prevention Committee."

Canada.

"Canadian Mining Journal."

United States.

"Journal and Chemical Abstracts of the American Chemical Society."
"Proceedings of the American Society for Testing Materials."
"Journal of Industrial and Engineering Chemistry."
"Mineral Industry."

Belgium.

*"Annales des Mines de Belgique."

France.

"Année Scientifique et Industrielle."
"Association de Bibliographie et de Documentation."
"Revue de Métallurgie."
"Revue Générale des Sciences."

Germany.

*"Chemiker Zeitung."
*"Ferrum."
*"Geologisches Zentralblatt."
*"Giesserei Zeitung."
*"Glückauf."
*"Stahl und Eisen."
*"Zeitschrift für angewandte Chemie."

* No numbers received since August 1914.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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In the preparation of these Notes the Editor has been assisted by L. P. SIDNEY, Assistant Secretary, and others.

IRON ORES.

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I.—*OCCURRENCE AND COMPOSITION.*

Origin of Iron Ore.—C. L. Dake[1] discusses the formation and distribution of residual iron ores which occur both as products of weathering and as products of hydrothermal decay. Weathering produces important accumulations of iron sediments in limestones and basic igneous rocks, but in other rocks such concentration is of minor importance. Hydrothermal decay has, on the other hand, produced iron-rich residual soils comparable with laterites, as in the Hawaiian Islands. Laterites, which by reason of their lower silica content and the nature of the parent rock, are richer in iron than ordinary residual clays, are developed only from basic igneous rocks and in tropical regions of heavy rainfall. Such laterites are widespread in the tropics and represent enormous concentration of residual iron. Indeed, in the formation of such residual deposits laterite weathering is probably a factor of the greatest importance.

K. von Mücke[2] has investigated the mineral deposits of Transylvania with a view to forming conclusions as to their origin, and his theory on the subject is briefly summarised. The region possesses abundant mineral wealth, but iron ore is comparatively scarce.

Iron Ore in France.—A description of the Landres iron ore mines in the Minette region of French Lorraine, accompanied by a map of the Concessions, is given by A. Dreux[3] in the course of an address of welcome to members of the Société de l'Industrie Minérale, visiting the district early last year.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 937–946.
[2] *Glückauf*, 1914, vol. l. pp. 1397–1400.
[3] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 20–39.

Iron Ore in Germany.—K. Oebbeke[1] describes the iron ores of the Upper Palatinate. Their occurrence, geological formation, and economic importance are discussed.

Iron Ore in Italy.—Bentz[2] gives an account of the geological conditions of Sardinia and of the iron ore deposits of that island. The methods of mining the ore, its economic importance and the trade in the export of iron ore are reviewed.

Iron Ore in Poland.—F. Bartonec[3] gives an account of the geological conditions of the south-eastern district of Poland. Iron ore deposits occur in the Keuper and Jura formations. The ores of the Keuper formation contain 36 to 39 per cent. of iron, which is increased, by roasting, to 49 to 50 per cent., while the manganese varies from 0·93 to 5 per cent. The Jura ores in the raw state run from 25 to 45 per cent of iron.

Iron Ore in Russia.—J. W. Revillon[4] describes the iron ore deposits in South Russia. The Krivoi Rog deposit, which is practically pure hæmatite, is a very rich one, which occurs as lenticular inclusions of varying thickness, sometimes up to 120 feet thick, between beds of very hard silicate of iron. The ore varies considerably in iron content in different localities, assaying at from 70 to 55 per cent. In 1912 about 5,250,000 tons of ore were raised in this district, which represents 67 per cent. of the total production of Russia. The Kertch deposit is a very extensive one, containing from 40 to 45 per cent. of iron.

In addition to the manganese ore deposits of the Caucasus, there are the Nicopol mines, situated in South Russia proper. In 1912 these mines produced about 240,000 tons, or 29·2 per cent. of the total manganese ore output of the country.

C. R. King[5] gives an account of the Krivoi Rog iron ore district. The ore occurs in the form of a bright hæmatite of high quality lying beneath the ferruginous quartzite and otherwise as a band between the ferruginous quartzite and the strata of argillaceous schists. In the first case the measure has a thickness of from 10 to 100 metres, and in the latter case it varies from 0·5 to 30 metres. The formation of the ore beds has been attributed to the process of metamorphosis of the augite, and it is believed that the measures of Krivoi Rog belong to this type of hydrochemical formation.

Iron Ore in Asia Minor.—F. Frech[6] reports on the mineral resources of Anatolia. After describing the geological conditions of this province, in which no great development has yet taken place, an account is given of the chromiferous iron ore deposits, which, according to previous investigators, are among the most important known. The richest veins lie near Brussa and Tchardy, the resources being estimated at 10 million tons, in which the ore runs at 51 to 55 per cent. of chromic oxide. The total output of chromiferous ore in Asia Minor was 28,860 tons in 1907. Hæmatite and brown iron ore also occur in abundance in the same neighbourhood, as well as many of the common non-ferrous metals.

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[1] *Bayerisches Industrie und Gewerbeblatt*, 1914, vol. xlvi. pp. 363-367.

[2] *Bergwirtschaftliche Mitteilungen*, November-December 1914, pp. 277-286.

[3] *Oesterreichische Zeitschrift*, 1914, vol. lxii. pp. 726-729.

[4] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 245-246.

[5] *Engineering Magazine*, 1914-15, vol. xlviii. pp. 481-492.

[6] *Glückauf*, 1915, vol. li. pp. 381-387, 412-418, 438-443, 464-470.

Iron Ore in China.—A description of the Chan-Si iron ores, which contain very high proportions of iron (76·77 per cent. of FeO, which is equivalent to 58·88 per cent. of iron), is given by Bordeaux.[1] The ore is formed in close proximity to valuable deposits of excellent coal of an anthracitic nature, while further south lower grade oolitic and hæmatite ores occur near to immense fields of bituminous coal.

Iron Ore in the Philippines.—Particulars are given[2] of an investigation of the iron ores of the Bulacan Province in the Philippine Islands, undertaken by F. A. Dalburg and W. E. Pratt. The investigation was undertaken with the idea of aiding the established Filipino iron-smelting industry. The iron ores of Bulacan are situated in the edge of the Eastern Cordillera of Luzon in an inaccessible and undeveloped region; the ore bodies are not continuous but are found at intervals over a distance of about 9½ miles. The largest ore body is at Camaching in the northern part of the region, but other deposits which may be of commercial importance are situated at Hizon, Santol, and Montamorong. The ores consist of magnetite and hæmatite in intimate mixture; quartz is the most abundant gangue mineral, but pyrite is also common. The ores which are mined at present average more than 60 per cent. of iron, but the bulk of the ore reserves is probably somewhat lower in iron. Phosphorus is below the Bessemer limit in most of the ores. Siliceous ores, which are not utilised at present, occur in considerable proportion. The ores are at present exploited in a small way by Filipinos, who produce cast-iron implements such as ploughshares directly from the ore by a primitive smelting process.

Iron Ore in Morocco.—A description of the geology of the Guelaya region, Melilla, in Spanish Morocco, and of the iron ore deposits found there is given by Brun.[3] Three deposits have been made, so far, the subjects of concessions; those of Riff, which nearly precipitated the war crisis of 1909 and resulted in the Moroccan question, those of a former German company now known as the Bilbao Company, and those of the Alicante Company. The ore occurs in veins and contains about 55 per cent of iron, and low (0·016 per cent.) phosphorus.

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[1] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 10–11.
[2] *Philippine Journal of Science; Iron and Coal Trades Review*, 1915, vol. xc. p. 474.
[3] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 350–365.

E. Brumder[1] publishes a descriptive account of the geological conditions of the iron ore deposits in the north-eastern Riff, Morocco. In particular the deposits of the Uixan range, of Ibercanen, of Maurico and of Rogelio are dealt with. The origin of the iron ore in the Uixan range is considered and the ore resources, conditions of ownership and export facilities are discussed.

Iron Ore in East Africa.—It is stated[2] that iron ore of the lateritic type occurs at the surface in various parts of German East Africa, and is smelted in a primitive way by natives at Ku Ndapa in the Livingstone Mountains, north-east of Lake Nyasa. In the Upanga district, hæmatite ore occurs. A sample of this gave ferric oxide 75·75 per cent. In the same region, and some miles to the south of the Ruhuhu, in the Mtambalala stream, spathic iron ore occurs, a sample of which gave ferrous oxide 47·95 per cent., lime 1·24 per cent., magnesia 0·60 per cent., alumina 1·57 per cent., carbon dioxide 27·04 per cent., phosphoric oxide 0·50 per cent., water 3·34 per cent., and insoluble residue 18·20 per cent.

More important than these perhaps are the magnetic iron ores, that occur in thick bands in the gneisses at various localities. Notable among these are the occurrences in the Uluguru range. On the western side of this range, at Hundussi, magnetite occurs, a sample of which gave magnetic iron oxide 65·52 per cent., titanium dioxide 1·85 per cent., and insoluble residue 30·88 per cent.

Magnetic iron ore and limonite occur also in the Ruanda district and other places in the region between the Victoria Nyanza and the northern end of Lake Tanganyika, where they are to some extent worked by natives.

Iron Ore in Canada.—E. Lindeman[3] describes the occurrences of magnetite near Calabogie, in Renfrew County, Ontario. The magnetite deposits of this district occur in bands and lenses associated with amphibolites; and they generally occur along or near the contacts of these rocks with crystalline limestone. The quality of the ore varies considerably, not only in the various mines, but also within the same ore body, owing to the amount of gangue-rock present. In some places it consists of fairly pure magnetite, and in others it contains considerable amounts of hornblende, mica, and chlorite. The best quality of ore averages about 61 per cent. of iron, while in other places it does not average more than 47 per cent. The sulphur content varies from 0·012 to 1·65 per cent., with the phosphorus ranging from 0·170 to 0·578, indicating that the ore is of non-Bessemer grade. Magnetometric surveys and actual mining work have shown that the deposits are of very irregular character. The larger deposits vary in width from 1 to 7 feet, with a maximum length of about 150 feet.

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[1] *Glückauf*, 1914, vol. l. pp. 1509–1514, 1533–1539, 1553–1560.
[2] *Bulletin of the Imperial Institute*, 1914, vol. xii. pp. 591–592.
[3] Canada, Department of Mines: Mines Branch, 1914, Report No. 254.

E. Lindeman[1] deals with the Moose mountain iron-bearing district, Ontario. In this district there are large deposits of low-grade magnetic iron ore, occurring in Pre-Cambrian schists. The ore consists chiefly of a fine-grained siliceous magnetite, interbanded with chert and quartzite. The percentage of iron varies up to about 45; and the average iron is between 30 and 40 per cent. A typical analysis is as follows:—

	Per Cent.
Fe	36·70
SiO_2	45·20
MnO	0·04
Al_2O_3	0·25
CaO	1·06
MgO	1·59
S	0·024

Tests have shown that by crushing the ore to 80 or 100 mesh, and passing it through a Gröndal magnetic separator, a concentrate of the following composition could be obtained:—

	Per Cent.
Fe	65·58
SiO_2	8·69
Al_2O_3	0·20
CaO	0·46
MnO	0·04
MgO	0·41
S	0·029
P	0·019

This concentrate, however, would require to be briquetted before it could be used in the blast furnace. Since it will be necessary to mine and crush to a fineness of 80 to 100 mesh about 2·2 tons of ore in order to obtain one ton of concentrate with 65 per cent. of iron, and adding to the cost of mining and concentration that of briquetting, it is evident that only by the most economic handling of the material, on a large scale, will it be possible to work these low-grade ores at a profit.

Iron Ore in New South Wales.—It is stated[2] that the ironstone used at the iron and steel works of the Broken Hill Proprietary Company, Newcastle, New South Wales, is obtained from Iron Knob, some forty miles from Port Augusta, where is situated the largest iron ore deposit in that State. The ironstone is contained in two great ore-bodies known as Iron-Knob and Iron-Monarch, the latter being the larger of the two. The average content of metallic iron in the ore is 68·5 per cent. The extent of the deposits has not yet been actually determined, but on the assumption that the average depth of ore is no more than 100 feet, it is calculated that over 21,000,000 tons of ore are available.

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[1] Canada, Department of Mines: Mines Branch, 1914, Report No. 303.

[2] *Journal of the Royal Society of Arts*, 1915, vol. lxiii. pp. 464–465.

Iron Ore in United States.—L. E. Ives[1] gives a description of the newly-found ore body near Crystal Falls, Michigan. Exploration work in certain areas was suggested in 1909 and a number of drill holes were put down. Although for some time no merchantable ore was found, a discovery was at last made which turned into a success that which appeared to be developing into a failure, and proceeding with a fresh conception of the geological conditions in view, success was finally achieved and exceedingly valuable bodies of high grade ore were located.

P. B. McDonald[2] gives an account of the iron ore reserves of Alabama. Only exceptionally do the ores contain over 50 per cent. of iron; the Clinton ores, which are the most numerous, averaging between 35 and 40 per cent. Much of the deposit has hardly as yet been opened up. The brown ores, which are better ores generally, are scattered throughout the Appalachian valley. The methods of mining and concentration employed are described.

G. M. Holmgren[3] states, from his personal investigations on the spot, that the percentage of iron in the ore smelted at the principal works of the Eastern States of the American Union had fallen during the previous ten years by about 6 per cent.

Iron Ore in Cuba.—J. F. Kemp[4] discusses the Mayari iron ore deposits of Cuba, with special reference to their mineralogical characters and their chemical composition. Reference is made to earlier reports showing the geological occurrence of the deposits, and typical analyses of ore from Moa and other regions are given, together with a diagram illustrating the physical and mineralogical changes that appear to have taken place in the serpentine during its passage to iron ore. The serpentine has undergone such thorough metamorphosis as to destroy most of the optical properties of the original, although it still displays prismatic cleavage. Microscopic sections are given of the three distinct layers of ore which occur in the pits, the upper of crimson-brown hue, the middle one yellowish-brown, and the bottom one of a lighter shade of yellowish-brown. In some places at the surface or a few feet below it, slabs and even continuous sheets of solid iron hydrate appear. This solid ore is called "plancha." The general run of the ore is, however, earthy and resembles, both in colour and texture, the Mesabi ores. When recently mined it has a peculiar mealy character, but as it dries out this character disappears. It is doubtless due to the colloid nature of the hydrates of alumina and iron. Typical analyses of three contrasted layers are given on next page.

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[1] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 443–445.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 759–764, and 790*c*.

[3] *Bihang till Jernkontorets Annaler*, 1914, pp. 221–246.

[4] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 129–154.

	I. Surface Ore. Sta. 11, 35, 10. Crimson-Brown.	II. Middle Layer. Sta. 11, 34, 10, and 15. Yellow.	III. Bottom Layer. Sta. 11, 35, 11. Yellow.
SiO_2	2·26	2·70	7·54
Al_2O_3	14·90	7·13	4·97
Fe_2O_3	68·75	71·89	64·81
Cr_2O_3	1·89	3·17	3·66
FeO	0·77	1·29	1·49
NiO	0·74	1·60	2·75
MgO	...	...	1·50
H_2O combined	11·15	12·90	12·75
Total	100·46	100·68	99·47
Metallic iron	48·65	51·32	46·52
Metallic nickel	0·59	1·20	2·10
H_2O absorbed[1]	4·62	9·72	27·00

It will be seen that the silica increases progressively from above downward, while the alumina decreases. The ferric oxide first increases and then declines. Analyses are also given of laterite ores occurring elsewhere, which are compared with Mayari ores. A very recent discovery of ore similar to the Mayari deposits has been reported from the northern portion of the Island of Mindanao, in the Philippines. It is a surface deposit produced by the tropical weathering of basic, igneous rocks. Reserves of 800,000,000 tons are estimated, and the ferric oxide runs as high as 77·7 per cent., corresponding with 54·4 per cent. of iron. Sulphur and phosphorus are present in traces only.

B. Orton[2] gives an account of the recent development of the principal iron ore deposits in Cuba. They lie for the most part on the southern slopes of the Sierra Maestra, a range running close to the southern coast towards the eastern end of the island. The principal ore fields are the Daiqueri fields with a present yearly production of 500,000 tons, the Juragua fields with a yearly production of 400,000 tons, and the El Cuero field, in which operations were only begun in 1910. The output in the first years was about 180,000 tons. Practically the whole of the ore mined goes to the American ironworks which own the mines. Some notes on the composition and character of the ore are given, and also an illustrated description of the ore handling and loading appliances.

Iron Ore in Brazil.—The leading Brazilian ore deposits are described by E. C. Harder.[3] The most important deposits are the hard dense hæmatites of Minas Geraes. An average analysis shows that these ores contain:—

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[1] Determinations of absorbed water based on original sample. Other determinations on dried sample at 110° C.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1731-1736.

[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2573-2586.

	Per Cent.
Iron	69·65
Phosphorus	0·0125
Silica	0·24
Combined water	0·38

Magnetite deposits also occur but are of relatively little importance, although in Sao Joao Baptista rich specimens containing up to 72·24 per cent. of iron have been encountered.

The area over which the Minas Geraes hæmatites are found extends roughly for 100 miles by 60 miles in width. Within this area the ore-bodies are more or less segregated at certain localities. The chief constituent of the iron formation is itabirite, weathering at the surface to a blanket consisting of itabirite and ore fragments cemented with limonite. Hard and soft ore occur as lenses or beds in the itabirite. The phosphorus is almost invariably low. The facilities for working and transportation and the labour conditions are briefly discussed.

Iron Ore in Chili.—C. A. Buck[1] gives an account of the production of iron ore from the Tofo mines during the year 1914. Exploration work was carried out by means of tunnels and the ore reserves materially increased. The quality was well kept up and there was no increase in sulphur. A sample from the lowest tunnel contained:—

	Per Cent.
Iron	67·47
Manganese	0·12
Phosphorus	0·008
Sulphur	trace
Silica	2·00

63,000 tons of ore were shipped during the year, 42,000 tons being consigned to Philadelphia, and 21,000 tons to Europe on behalf of a French company. The plant is to be increased until an annual production of 1½ to 2 million tons is reached. A description of the latest appliances and ore handling plant is given.

Iron Ore in Venezuela.—The mineral resources and iron industry of Venezuela are described.[2] Iron ore deposits occur on the northern slopes of the Sierra Imataca, in Venezuelan Guiana, on the southern tributary of the Orinoco, from the mouth of which river they extend eastwards about 300 kilometres. The iron ore beds in many places are said to exceed 60 feet in thickness, and in 1913 about 55,000 tons of iron ore (magnetite and hæmatite) were exported to the United States.

Iron Ores containing Arsenic.—The occurrence of iron ores containing arsenic and the treatment of such ores form the subject of an address by Mathesius.[1] The principal occurrences of such ores are in Spain, Greece, and particularly in Asia Minor, near Smyrna. The deposits in the latter locality consist of a 60 to 65 per cent. iron ore with arsenic running from 0·3 to 2 per cent. Large quantities are also found in Algiers and Tunis.

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[1] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 145–146.

[2] "Berichte über Handel und Industrie, 1915," *Stahl und Eisen*, 1915, vol. xxxv. p. 457.

Chrome Ore.—S. H. Dolbear[2] refers to the occurrence of chrome ore in California. Formerly about 40,000 tons have been produced, but the output declined when faced with the competition of the New Caledonia deposits. In the circumstances now prevailing the industry may be anticipated to develop.

A. E. V. Zealley[3] describes the geology of the chromite deposit at Selukwe, Rhodesia. Chromite is distributed through the talc-schists and serpentines, at Chrome Hill and Selukwe Peak. Over 103 lenses have been mapped out on the surface at various points, ranging from 150 to 450 feet in length, many of which may be worked by ordinary quarrying methods.

Manganese Ore in Russia.—In a review of the mineral resources and industries of Russia, C. R. King[4] refers briefly to the manganese ore mining industry. The chief deposits are near the city of Nicopol, in the Ekaterinoslav Province, and the ore is of the pyrolusite type (MnO_2). The maximum production was reached in 1907, in which year it amounted to 269,584 tons.

Manganese Ore in Spain.—R. Pilz[5] discusses the origin of the manganese ore deposits at Huelva, in Spain. The ores of this district are characterised by the fact that they are always found in combination with siliceous schist.

Manganese Ore in the United States.—C. Hafer[6] notes the occurrence of manganese ore at the old Dorn mine at McCormick, South Carolina. This was formerly a gold mine. Veins of manganese averaging 41 per cent. of manganese occur. Outcrops of manganese ore also occur across the Savannah River, in Georgia, at the Magruder mine.

The manganese ore deposits of California are briefly described by S. H. Dolbear.[7] By care in mining, an ore containing 75 to 80 per cent of MnO can be obtained. The industry requires capital for its development. The Noble Electric Steel Company at Heroult, California, is now equipping two of its furnaces for the production of ferro-manganese, and other developments are taking place.

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1694–1695.

[2] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 720–722.

[3] Paper read before the Geological Society of South Africa; *Mining Magazine*, 1915, vol. xii. pp. 108–109.

[4] *Engineering Magazine*, 1914–15, vol. xlviii. pp. 481–492.

[5] *Zeitschrift für praktische Geologie*, 1914, vol. xxii. pp. 373–377.

[6] *Engineering and Mining Journal*, 1914, vol. xcviii. p. 1135.

[7] *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 721.

Manganese Ore in Cuba.—According to B. Orton[1] some important deposits of manganese ore exist in Cuba, though the ore is not very high grade. The best quality contains 42 per cent. of manganese, 0·08 of phosphorus, 11 of silica, 6 of iron, and 10 per cent. moisture.

Molybdenum Ore.—W. H. Smith[2] describes the Canadian molybdenite deposits. They occur widely distributed throughout Ontario and Quebec, as well as in Nova Scotia, New Brunswick, British Columbia and the Yukon territory. Molybdenum is found in small bunches and short narrow stringers, disseminated mineral being rarely seen. In British Columbia it is obtained in massive form which, when free from gangue, constitutes a most valuable ore. The Ontario and Quebec deposits vary in their content from 1½ to 5 or 6 per cent. molybdenum. In many cases a certain amount of clean, flake material can be hand picked so as to contain 98 to 99 per cent. pure sulphide.

The sources and uses of molybdenum ores are briefly dealt with.[3]

Titanium Ores.—T. L. Watson[4] and S. Taber describe the titanium and apatite deposits of Virginia.

Tungsten Ores.—The wolframite deposits of Lower Burma are described by E. M. Lefroy.[5] The deposits occur principally in the district of Tavoy, the grade of wolframite being a high one, varying from 60 to 70 per cent. of tungstic acid. Chinese labour is at present employed, but hydraulic mining will soon be installed. Many other rare minerals occur in Burma, but, owing to the heavy rains from May to November, prospecting is carried on with difficulty. The production for the year ending March 31, 1914, was 1622 tons of wolframite and 68 tons of cassiterite.

The occurrence and output of tungsten are dealt with.[6]

Uranium Ores.—E. T. Wherry[7] describes an occurrence of carnotite in a conglomerate rock at the eastern termination of Mount Pisgah, near the town of Mauch Chunk, Pennsylvania. An analysis shows that the carnotite contains 21·73 per cent. of vanadic oxide, 68·99 per cent. of uranium oxide, 7·86 per cent. of potash, and 1·42 per cent. of lime. It is considered doubtful, however, whether the deposit, regarded as a whole, contains over 1 per cent. of uranium oxide.

[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1731-1736.
[2] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 271-272.
[3] *Canadian Mining Journal*, 1915, vol. xxxvi. pp. 233-234.
[4] Virginia Geological Survey, 1913, *Bulletin III.-A.*
[5] *Engineering and Mining Journal*, 1915, vol. xcix. p. 684.
[6] *Engineering*, 1915, vol. xcix. pp. 442-443.
[7] United States Geological Survey, 1914, *Bulletin* No. 580-H.

E. S. Simpson[1] describes the occurrence of uranium ore at Wodgina, Western Australia.

Vanadium Ores.—G. W. McGhee[2] describes a new vanadium deposit in Baraga County, Michigan. The ore is a soluble silica, blue-black in colour, carrying in addition to vanadium a small percentage of uranium and about 1 per cent. of iron. The vanadium content is about 21·5 per cent.

E. S. Simpson[3] describes the distribution of vanadium and molybdenum in Western Australia. Vanadium has already been proved to be widespread in small quantities, particularly in the ancient greenstones, laterites, clays, and in coal ashes. The ashes from Collie coal contain from 0·02 to 0·21 per cent. of $V_2 O_5$.

Meteoric Iron.—G. T. Prior[4] finds that the meteoric stone of Uwet, Southern Nigeria, said to have fallen about 90 years ago, is a hexahedrite of the Braunau type, containing about 6 per cent. of nickel. The meteoric stone of Kota Kota, British Central Africa, which fell some years ago, is a chondrite, probably belonging to the crystalline spherulitic group. The meteoritic iron of Angela, near Iquique, Chili, which was found in the nitrate deposits, is an ataxite, containing 4·5 per cent of nickel, and enclosing large nodules of schreibersite.

W. M. Foote[5] describes a meteoric iron found in Sams Valley, Oregon, in 1894. The mass is irregularly lenticular in contour, and its total weight was about 15¼ lbs. On polishing and etching a slice of the mass, the crystallisation of a medium octahedrite was clearly brought out. Schreibersite is abundant in small masses, but mostly in the form of broad, thin plates showing on the etched surface as slender rods of about 0·1 to 1 millimetre in width and 10 to 30 millimetres in length. These plates sometimes lie between the kamacite lamellæ, but more often cut across the squares prominently at various angles. Parallel to these plates for their entire length runs the typical and familiar swathing kamacite of Brezina. The kamacite bands, which are about double the thickness of the normal kamacite forming the crystalline mass, are quite regular, except for those paralleling the schreibersite plates. Very thin lamellæ of nickel-rich tænite outline all the kamacite bands, and the ground mass consists of abundant fields of nickel-poor plessite.

O. C. Farrington[6] gives an account of several new meteorites that have been added to the collection of the Field Museum in Chicago. These include the Ahumada iron, found 60 miles east of Ahumada,

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[1] Western Australia Geological Survey, 1912, *Bulletin* No. 48, *Miscellaneous Report* No. 9.

[2] *Mining and Engineering World*, 1914, vol. xli. p. 1088.

[3] Western Australia Geological Survey, 1914, *Bulletin* No. 59, *Miscellaneous Report* No. 35, pp. 31–56.

[4] *Mineralogical Magazine*, 1914, vol. xvii. pp. 127–134.

[5] *American Journal of Science*, 1915, 4th Series, vol. xxxix. pp. 80–86.

[6] *Field Museum of Natural History, Geological Series*, 1914, vol. v. No. 1.

Mexico, in 1909, weight 116 lbs.; the Bishop Canyon iron, weighing 19 lbs., found in 1912 near Bishop Canyon, Colorado; a large iron weighing 1520 lbs., found in 1903 at the north end of Davis Mountains, Texas. This last iron is remarkable in that it contains the largest amount of platinum thus far recorded (0·03 per cent.).

E. S. Simpson[1] describes two new meteorites from Western Australia. The one found near Mount Dooling is a typical siderite, but composed for the most part of nickel-iron alloys. Its total weight was 69 lbs.

The second meteorite, which was found at Premier Downs, weighed 112 grammes, and is an entire body, showing no evidence of fracturing, the whole surface being covered with a smooth, rounded, black and brown film of iron oxides. The following shows the composition:—

	Per Cent.
Iron	91·68
Nickel	7·46
Cobalt	0·64
Phosphorus	0·21
Sulphur	0·04
Silicon	0·01
	100·04

E. S. Simpson[2] and H. Bowley also describe a second meteorite which was found in 1911 at Premier Downs, Western Australia. It presents at first sight many resemblances to that first found. It weighs 116 grammes, and contains 88·51 per cent. of iron and 7·58 per cent. of nickel.

E. S. Simpson[3] also describes a large meteorite, weighing approximately 350 lbs., which was found in 1913 in the vicinity of Mount Edith, Western Australia.

A. Brezina[4] shows the structure of the Nuleri meteorite which was found in Western Australia in 1902.

II.—*IRON ORE MINING.*

Mine Surveying.—T. Simons[5] challenges the claims made on behalf of the "Faultless Faultfinder," and gives diagrams showing how alternative methods of charting may be made to give better results. W. S. Weeks[6] and E. V. Huntington reply to the criticisms made.

The method of triangulating from two plumb wires is discussed and illustrated by A. G. Wolf.[7]

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[1] Western Australia Geological Survey, 1912, *Bulletin* No. 48, *Miscellaneous Report* No. 18.

[2] *Ibid.*, 1914, *Bulletin* No. 59, *Miscellaneous Report* No. 47, pp. 205–209.

[3] *Ibid.*, pp. 210–212.

[4] *Ibid.*, pp. 213–214.

[5] *Engineering and Mining Journal*, 1914, vol. xcviii. pp. 884–887.

[6] *Ibid.*, p. 887.

[7] *Ibid.*, pp. 1043–1044.

Magnetic Surveying.—J. E. Rotthaus[1] deals with the application of magnetic methods of surveying on the Cuyuna iron ore range. The hæmatite is practically non-magnetic, while the accompanying slates carry magnetite and attract the needle. Crude methods therefore yield better results than those of refined accuracy such as are used in Sweden. Gurley's "Miner's Dip Compass No. 341" is used, and the methods of making observations with this instrument are described and illustrated.

Rock Drills.—A series of articles by L. O. Kellog[2] dealing with the chief types of modern American rock drills and illustrated with numerous examples has appeared.

The Ingersoll-Rand Jackhammer auger drill recently introduced on the Mesabi range and intended to supersede hand-drilling and blasting is described.[3]

C. A. Hirschberg[4] presents a record of experience with various types of rock drills.

M. L. Requa[5] institutes a comparison of the relative costs of rotary and standard drilling, with special reference to petroleum practice in California.

The design and application of rock hammer drills are dealt with by B. F. Tillson.[6]

Methods of Working Iron Ore.—L. E. Ives[7] describes the use of electric shovels in iron ore mining in Lapland. The Luossavaara-Kirunavaara Company, which operates mines 80 miles north of the Arctic circle, has adopted Bucyrus shovels of 100 tons capacity, electricity being obtained from water-power at Porjus Falls, one of the greatest water-power resources in Sweden. Cutler-Hammer controllers of the series relay type are usual for operating the shovels, of which three are at present installed. The ore-handling appliances at the mines and at Lulea, the port of shipment, are also described.

L. E. Ives[8] also deals with stripping by drag-line excavators and Bucyrus shovels in the Menominee ore district and compares their relative advantages. These tend to preponderate in favour of drag-line excavators.

Some unusual problems in open pit mining met with in the Virginia mine, Virginia, Minnesota, where the composition of the ore varies widely even in the same bank, and the methods of dealing with them, are discussed by J. H. Eby.[1]

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[1] *Engineering and Mining Journal*, 1914, vol. xcviii. pp. 603–604.

[2] *Ibid.*, pp. 687–688, 747–751, 771–775, 821–823, 864–867, 909–912, 995–1000, 1040–1041, 1071–1073.

[3] *Ibid.*, pp. 745–746.

[4] *Mining and Engineering World*, 1915, vol. xlii. pp. 759–764.

[5] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 217–219.

[6] *Ibid.*, pp. 505–528.

[7] *Engineering and Mining Journal*, 1914, vol. xcviii. pp. 767–769.

[8] *Ibid.*, pp. 941–943.

The first open cast operations on the Menominee range are recorded by R. V. Sawhill.[2] Drag-line excavators are being used for the Balkan mine, at Mastodon, where the overburden consists of quick sand, to a depth varying from 15 to 80 feet, and where the problem of handling the water threatened difficulties. The stripping contract called for the removal of 1,200,000 cubic yards, and each excavator loads over 1000 cars in ten hours.

A new form of iron ore shovel, specially designed for underground work, and used in the iron ore mines of Alabama with great success, is described and illustrated.[3] With a shallow track and a low car work can be done in a 50-inch tunnel, and a machine of 10 horse-power has a capacity of 30 cubic feet per minute, and can load from 10 to 20 tons of ore in an hour.

G. E. Edwards[4] reviews recent progress in mining operations on the Lake Superior iron ranges.

Haulage in Iron Mines.—H. Nathorst[5] gives a further account of compressed-air locomotives made for Swedish mine-owners. Gauges of 500, 600, and 750 mm. are used, and the pressure in one instance is 40 atmospheres. The greatest length of journey is 984 yards, and thirty trips were made for eight hours, moving in that time 255 tons of ore.

Winding Plant for Iron Mines.—W. Pickersgill[6] gives an illustrated description of the new winding installation for the Bavarian iron ore mines of the Deutsch-Luxemburg Mining and Ironworks Company.

Ventilation of Iron Ore Mines.—The proper ventilation of iron ore mines is discussed in its economic aspects by E. Higgins,[7] who points out that so far as impure air vitiates the miner and impairs his efficiency, the adequate ventilation of iron ore mines is attended with a reduction in the cost, per ton, of the iron ore produced.

Safety Appliances in Iron Ore Mining.—E. Higgins[8] summarises the work of the various organisations and institutions engaged in promoting safety in the iron mines of the Lake Superior district. The various bodies each cover well-defined sections of the work, although, to a certain extent, their activities also overlap somewhat. The benefit which has accrued through their instrumentality is, however, clearly demonstrated by the reduced percentage of fatal accidents during recent years.

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[1] *Michigan College of Mines*, "*Alumnus*," April 1914; *Engineering and Mining Journal*, 1914, vol. xcviii. pp. 609–610.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 636–638 and 654*c*.

[3] *Ibid.*, pp. 200–201.

[4] *Mining and Engineering World*, 1915, vol. xlii. pp. 449–459.

[5] *Bihang till Jernkontorets Annaler*, 1915, pp. 64–71.

[6] *Zeitschrift des Vereines deutscher Ingenieure*, September 26, 1914, vol. lviii.

[7] Paper read before the Lake Superior Mining Institute, August 1914; *Iron Trade Review*, 1914, vol. lv. pp. 429–430 and 454*b*.

[8] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2515–2530.

E. Higgins[1] gives some suggestions for the organisation and conduct of safety work in metal mines.

E. Higgins[2] calls attention to the chief causes of accidents from explosives in metal mines and suggests means for their prevention.

Handling Iron Ore.—A. Varty[3] deals with the dumping of refuse by aerial ropeway, and describes the plant which is in operation at the Liverton Mines, Loftus, where a seam of ironstone is being worked. The length of the line is at present 550 yards, but is being extended to 910 yards. It is a single rope system, and is designed for 50 tons per hour.

A new system of electric carrier for conveying ores is described.[4] The cars are propelled by magnetic force created between the shifting field of the primary on the car, and the induced current in the secondary between the rails. The cars are built of a size and design to the requirements of any particular traffic, and are operated without motormen.

A description is given[5] of the ore-handling plant of the Wheeling and Lake Erie Railroad at Lake Huron, Ohio. There are two Hulett unloading machines of 15 tons capacity each, operated by steam and hydraulic power.

J. E Little[6] describes a series of tests of inclined cables at the Mayari iron mines in Cuba. The conditions of operation require a cable having a working strength of about 150,000 lbs. The cables are carried along the track on cast manganese steel rollers with rolled manganese steel axles cast in, the axles running in rough cast-iron half bearings. After three years' service the original manganese steel rollers show no apparent wear. The tensile strength per square inch metallic area in cable section has been found to be from 175,000 to 182,000 lbs., while the actual strength of the wires varies from 728,000 lbs. to 751,000 lbs.

The ore-handling and loading appliances at the Cuban iron ore mines and at Santiago are illustrated and described by B. Orton.[7]

Economics of Iron Ore Mining.—P. Nicou[8] gives the text and discusses the purport of the State contracts entered into during the years 1907, 1908, and 1913, between the Swedish Government and the iron ore mining companies controlling the mines of Gellivara,

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[1] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 347–363.
[2] *United States Bureau of Mines*, 1914, *Miners' Circular* No. 19.
[3] *Iron and Coal Trades Review*, 1915, vol. xc pp. 295–297.
[4] *Mining and Engineering World*, 1914, vol. xli. p. 954.
[5] *Railway Review*, 1914, vol. lv. pp. 592–594.
[6] *Journal of the Engineers' Society of Pennsylvania*, 1914, No. 12, vol. vi.
[7] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1731–1736.
[8] *Bulletin de la Société de l'Industrie Minérale*, 1914, Series V., vol. vi. pp. 113–135.

Grangesberg, and Kirunavaara. The rights retained by the State and the privileges accorded the mining companies are reviewed and criticised.

J. D. Kendall[1] discusses some of the conditions affecting the value of ore mines.

V. G. Hills[2] gives some notes on mine-sampling.

III.—*MECHANICAL PREPARATION.*

Crushing of Iron Ore.—H. Stadler[3] deals with the theoretical considerations which underlie crushing practice as applied to ores, minerals, and other substances. The laws of crushing have been variously stated by Rittinger, who states that the work of crushing varies as the surface exposed during crushing; and by Kick, who states that it varies as the ordinal numbers of any regular reduction scale at constant ratio. Theoretical considerations derived from the known physical and mechanical laws involved tend to support the validity of the latter contention. Applications of the theory are discussed.

Ore Washing.—W. John[4] describes and illustrates the apparatus in use for washing brown iron ore in the district of Bilbao. Besides the brown iron ore, known generally as "rubio," which occurs in primary deposits, there is another kind known as "chirta," occurring in secondary formation and embedded in clay. Large revolving washing drums are used to get rid of the clay adhering to the ore, the daily yield of washed ore by one drum being 50 to 80 tons. Some fifteen mines are equipped with such washing installations.

Ore Drying.—C. O. Bartlett[5] deals with the mechanical drying of ore products, and illustrates a number of drying ovens.

Magnetic Separation.—The magnetic separation of ores of alloy metals is dealt with.[6] The increased demand for ferro-alloys in the production of high-grade steel has led to the necessity of closer attention to the percentages of purity in the ores used for these alloys. The following are fairly representative of the requirements now insisted upon. Tungsten ores require to be quite free from tin, with which they are generally found in combination, and should have at least 67 per cent. of tungstic acid, with not more than 3 to 5 per cent. of silica. Molybdenum ore, in the form of molybdenum sulphide, should contain 80 per cent. metal. Chrome ore should contain 52 to 55 per cent. of chromic acid. Most substances are magnetic to some degree, though naturally none of the non-ferrous ores have the same degree of magnetic conductivity as iron. In the United States several forms of electrostatic separators have been evolved and are in use, but in other parts of the world this type of separator is not favoured. The practice in Europe is mainly with electro-magnetic machines using either permanent magnets or "excited" magnets.

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[1] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 142–154.

[2] *Ibid.*, pp. 262–274.

[3] *Engineering and Mining Journal*, 1914, vol. xcviii. pp. 905–908, 945–948.

[4] *Glückauf*, 1915, vol. li. pp. 57–59.

[5] *Mining and Engineering World*, 1914, vol. xli. pp. 1175–1177.

[6] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 190–193.

H. Comstock[1] describes the new ore concentration plant at the Barton Hill Mine, Mineville, New York, which has been reopened after an abandonment of about twenty-two years. The deposit consists of coarsely crystalline magnetic ore, and contains about 35 per cent. of iron and 0·085 per cent. of phosphorus. The concentrates, on the other hand, contain 65 per cent. of iron and 0·018 per cent. of phosphorus.

I. C. Clark[2] deals with the general principles underlying electro-magnetic ore separation. Electro-magnetic ore separation depends upon differences in magnetic permeability. All known substances are either paramagnetic or diamagnetic, the great majority being diamagnetic. The chemical composition of minerals may occasionally serve as a guide to their magnetic properties. Many types of magnetic separators are in use, most of them using electro-magnets. The type of separator to be used in any particular case depends upon the class of minerals treated. The separation of magnetite from gangue material and impurities is the most extensive branch of the process, and forms an important industry in the eastern part of the United States and in several European countries.

S. Shapira[3] also deals with magnetic concentration processes as carried out by the Empire Steel and Iron Company of Catasauqua, Pennsylvania, with special reference to the employment of Ball and Norton magnetic separation machines. The analyses of the concentrates produced is as follows:—

Ore dried at 212° *F.*

	Per Cent.
Iron	58·000 to 60·000
Phosphorus	0·552 ,, 0·650
Sulphur	0·042 ,, 0·055
Manganese	0·025 ,, 0·050
Silica	8·000 ,, 10·000
Alumina	1·250 ,, 2·000
Lime	2·500 ,, 3·000
Magnesia	1·500 ,, 2·000
Titanium	trace ,, 0·350
Vanadium	0·035 ,, 0·750

Particulars are given[4] of an electro-magnetic separator for treating feebly magnetic ores. This machine has been designed by the Rapid Magnetting Machine Company of Birmingham.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 253–256.

[2] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 523–528.

[3] *Ibid.*, pp. 559–565.

[4] *Iron and Coal Trades Review*, 1915, vol. xc. p. 749.

Briquetting Iron Ore.—The ore-briquetting plant of the North-western Iron Company at Maryville, Wisconsin, is described.[1] The crude ore is like those of Alabama, with high phosphorus and silica. It is briquetted on the Gröndal system, four kilns being employed and the fine ore separated by screening from the lump. The comparative analyses of the crude ore and of the briquettes are shown below :—

	Ore.	Briquette.
	Per Cent.	Per Cent.
Iron	40·83	51·25
Phosphorus	1·45	1·63
Manganese	0·11	0·14
Silica	4·40	5·41
Alumina	3·33	4·45
Lime	6·02	7·72
Magnesia	2·75	3·05
Moisture	12·40	...
Loss	12·75	...

As the breeze used for briquetting caused the briquettes to fuse at too low a temperature, Greenawalt sintering pans have been introduced, with highly satisfactory results. They are heated by means of kerosene.

IV.—*METALLURGICAL PREPARATION.*

Roasting Kilns for Spathic Ore.—W. John[2] gives an account of the shaft kilns in use in the Bilbao iron mining district for roasting the spathic ores (carbonato) mined in that neighbourhood. The kilns of the Orconera Iron Company are about 40 feet high, and have an internal diameter of about 13 feet. The daily yield of one kiln varies from 56 to 78 tons according to the conditions of the natural draught, which varies according to the direction of the wind. The coal consumption varies between 0·5 and 0·8 ton, per ton of roasted ore.

Nodulising Iron Ore.—The iron ore nodulising plant of the North Carolina Company at Winston-Salem, is described.[3] The plant has a capacity of over 100 tons a day, and treats the pyrite residue obtained from sulphuric acid plants, the finished ore being supplied to the blast-furnaces in Virginia. The nodulising kiln consists of a steel cylinder 100 feet long, 8 feet in diameter, lined with firebrick, the lining having a thickness of 9 inches at the discharge end. The kiln is kept slowly in motion by a 50 horse-power motor, and powdered coal is blown through the discharge end and burned at a sufficiently high temperature to eliminate most of the sulphur and to agglomerate the iron oxide into solid nodules up to 1 inch in size.

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[1] *Iron Trade Review*, 1914, vol. lv. p. 289–291.
[2] *Glückauf*, 1915, vol. li. pp. 59–59.
[3] *Mining and Engineering World*, 1915, vol. xlii. pp. 415–416.

REFRACTORY MATERIALS.

Influence of Steam on Magnesite Brick.—R. H. Youngman[1] discusses the effect of steam on magnesite brick and calcined magnesite. When exposed to steam even the most thoroughly burned brick will hydrate and disintegrate, and difficulties of this nature are met with sometimes in open-hearth furnace bottoms when the bricks and magnesite are laid over a bed of refractory materials which have been mixed with water. On heating up, steam is formed, and the bottom may be badly damaged by hydration. The same thing happens while burning the bricks if any leakage of steam obtains access to them during the process.

Kieselguhr Bricks.—While from the point of view of heat insulation, infusorial earth or kieselguhr has long been recognised as a highly valuable material, practical difficulties have prevented its being used to make bricks. Such a brick is now, however, available. It is made from a mixture of kieselguhr, a small amount of clay and finely ground cork, moulded while wet, and then dried and fired. The cork burns out, leaving a light, porous brick the fusing point of which is 1600° F. and the crushing strength 140 lbs. per square inch. It also resists moisture well.[2]

Testing Firebricks.—M. Gary[3] has prepared a report on the testing of firebricks, and gives a full description of the methods and apparatus in use for this purpose at the Royal Testing Institute, Gross-Lichterfelde. The expansion, where exposed to heat, is determined by placing a small rod of 25 millimetres square section with semi-cylindrical ends in a Heræus furnace which is slowly heated up to 1200° C. The temperature is controlled by a Le Chatelier pyrometer. The alterations in length of the rod are measured by means of two small telescopes, the vertical hair-lines of which are adjusted so as to be tangential with the two cylindrical ends. The melting point is determined in an electric resistance furnace of special construction, particulars of which are given, and an optical pyrometer is used to read the melting temperatures. The resistance of the material to pressure when hot is also measured in a Heræus furnace, the tube of which is placed vertically on an asbestos-covered plate, while the specimen is held between an upper and a lower porcelain cylinder. The upper cylinder projects beyond the furnace tube and the pressure is applied to its upper flat surface. Another appliance fitted with an emery wheel is used to ascertain the resistance to wear.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 620; *Iron Trade Review*, 1914, vol. lv. pp. 683–684.

[2] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 129.

[3] *Mitteilungen aus dem Kgl. Materialprüfungsamt, Berlin-Lichterfelde; Stahl und Eisen*, 1914, vol. xxxiv. pp. 1461–1463.

Tests of Refractory Material.—F. Juretzka[1] gives some general information on the uses of hollow vessels of highly refractory material, with special reference to the manufacture of muffles. Methods of testing refractory materials as to their resistance to heat, mechanical strength, heat conductivity and permeability by gases are described.

Corrosion of Refractories at High Temperatures.—A. B. Searle,[2] in dealing with the corrosion of refractories by salts in coal, states that the chief variations which may occur are—(*a*) Temperature of the face of the firebrick in contact with the coal or coke, (*b*) Duration of the heating in contact with coal or coke, (*c*) Chemical nature of the corrosive in the coal or coke, (*d*) Chemical nature of the refractory material and the reaction between that and the salts, (*e*) Physical nature of the refractory—particularly the closeness or openness of the texture and the size of the grains, (*f*) Presence of adventitious materials, such as water and sulphurous acid gas, which may enter into reactions. In order to understand the corrosive nature of these compounds, it is necessary to realise that clays and silica are both extremely powerful acids when at a sufficiently high temperature.

Heat Conductivity of Refractory Materials.—P. Goerens[3] and J. W. Gilles have investigated the heat conductivity of firebricks, for which purpose they have devised a special apparatus, by means of which the heat conductivity of material in the form of ordinary bricks can be measured up to a temperature of about 1100° C. The conductivity of various products was determined at temperatures ranging up to 1000°, and the values obtained show clearly that the coefficient of conductivity increases with rising temperature in fireclay, lias, silica, and carbon. With magnesite, on the contrary, the coefficient is diminished as the temperature rises. In corroboration of their results the actual and apparent specific gravities of the several materials were determined and the porosity, equal to the difference between them, was calculated. The actual specific gravity was ascertained after crushing the material into fine powder so as to remove all porosity, the apparent being the specific gravity of a unit volume of the product as manufactured. The coefficient of heat conductivity decreases the greater the degree of porosity, while materials of high specific gravity are good heat conductors.

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[1] *Feuerungstechnik*, 1915, vol. iii. pp. 105–109, 120–123.
[2] *Journal of Gas Lighting; Iron and Coal Trades Review*, 1915, vol. xc. p. 401.
[3] *Ferrum*, 1914–15, vol. xii. pp. 1–11, 17–21.

B. Dudley, Jun.,[1] reviews the methods which have been devised to measure the heat conductivity of refractory bricks, and describes an investigation carried out by himself, on fireclay brick, silica brick with clay bond, silica brick with lime bond, and magnesite brick.

G. H. Brown[2] has carried out tests on the relative thermal conductivities of silica and clay refractory bricks. Three samples were tested, their composition being:—

	Silica Brick per Cent.	Quartzite Brick per Cent.	Clay Brick per Cent.
SiO_2 . . .	95·48	83·36	63·24
Al_2O_3 . . .	1·92	11·79	32·97
Fe_2O_3 . . .	1·42	1·69	1·33

Readings were taken up to 1300° C. The relative thermal conductivities of the bodies silica, quartzite, and clay were found to be as 1017 : 986 : 933, silica brick thus having a conductivity of 9·0 per cent. and quartzite 5·7 per cent. greater than that of clay.

Electric Resistance of Refractory Materials.—C. Hering[3] discusses the physical aspects of the variations in electric resistance of various refractories at high temperatures, and gives curves showing the comparative resistivity of different substances. A detailed list of the melting points, temperature coefficients, and resistivities of the principal refractories in use, as well as of the chief industrial metals, is given, as well as diagrams and curves recording observed data in the direction required.

Composition of Graphite.—E. Donath[4] and A. Lang have carried out an investigation on graphite both qualitatively and quantitatively. Methods for the determination of the carbon and sulphur are given. The amount of ash and its composition are of great importance in judging the value of graphite. The higher the ash content, the lower is the heat resistance of the graphite, because the ash is qualitatively so constituted that at high temperatures it is apt to sinter. The analysis of the ash can be best performed by the methods followed in analysing clays. The determination of the point of combustion of various kinds of graphite is then described, and the chemical behaviour of the carbonaceous substances which are used, or can be used, for the adulteration of graphite is considered. The loss on ignition of pure and adulterated graphite is shown as follows:—

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[1] Paper read before the American Electrochemical Society; *Iron and Coal Trades Review*, 1915, vol. xc. p. 772.

[2] *Transactions of the American Ceramic Society*, 1914, vol. xvi. pp. 382–385.

[3] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 23–28.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1757–1761, 1848–1851.

Ceylon graphite (pure)	15	per cent.	loss on ignition.
,, ,, mixed with coke	21	,,	,,
,, ,, ,, retort carbon	29	,,	,,
,, ,, ,, anthracite	53	,,	,,
,, ,, ,, acetylene soot	33	,,	,,
,, ,, ,, wood charcoal	49	,,	,,

The reactions of these substances with graphite are shown in tabular form, and a regular method for their detection in graphite is described.

Magnesite.—L. C. Morganroth[1] deals with the occurrence, uses, and properties of magnesite. The two chief types are massive and crystalline, massive magnesite occurring in serpentine, and being widely distributed, the deposits in Euboea, Greece, being probably the most important. Generally speaking, however, the veins of massive magnesite occurring elsewhere are too thin to work. Crystalline magnesite, on the other hand, is found only in Austria-Hungary, where it occurs in the dolomite to which it owes its origin. The mode by which it becomes metamorphosed is explained. The largest deposits are found near Veitsch, in Austria, where they occur as a huge lens found on an isolated hill surrounded on all sides by barren rock. The entire top of the hill is magnesite, and from the top to the base of the magnesite the depth is from 700 to 800 feet. The material is quarried by blasting. Caustic magnesite, or magnesite which has not been thoroughly calcined and still contains 3 to 4 per cent. of carbon dioxide, is mixed with magnesium chloride to form artificial marble and various kinds of hard-drying cements. Dead-burned magnesite, on the other hand, contains less than 1 per cent. of carbon dioxide, and has been so thoroughly calcined that there is no deterioration, or reversion by absorption, on exposure to air. Such material is used solely as a refractory. Good magnesite brick will last, in practice, a year or two, and is far the best material for open-hearth linings.

The magnesite deposits of Radenthein, Austria, acquired by the Austro-American Magnesite Company, are briefly described.[2] The annual production of calcined magnesite is 75,000 tons, and a brick-works is under construction which will have a capacity of 15,000 9-inch bricks per day.

The magnesite deposits of Castiglioncello in the Monti livornesi are described by G. D'Achiardi.[3]

Bauxite.—Bauxite, as obtained in the raw state, contains a high percentage of chemically-combined water as well as a large quantity of moisture.[4] It is thus necessary to calcine it at a high temperature before incorporating it with the material with which it is to be moulded. There are two distinct types of bauxite available, namely, white bauxite and red bauxite. The first type is akin to kaolinite in composition, whilst the latter is much richer in alumina, and also higher in iron oxide. The following are analyses of the two types:—

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2345–2352.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 772–773.

[3] *Rassegna Mineraria*, 1914, vol. xli. pp. 93–94.

[4] British Clayworker; *Foundry Trade Journal*, 1915, vol. xvii. p. 80.

	White Bauxite per Cent.	Red Bauxite per Cent.
Alumina	45	54
Silica	24	16
Iron oxide	1	2·5
Titanium oxide	4	6
Lime and magnesia	0·25	0·5
Water	25	21

The refractoriness of the white bauxite corresponds to 3200° F. and of the red to 3500° F.

Asbestos.—The asbestos resources of Southern Quebec are described by J. A. Dresser.[1] The annual production represents over 80 per cent. of the total production of the world. The asbestos in Southern Quebec occurs as a chrysolite variety having the same chemical composition as serpentine in basic igneous rocks of Cambrian, Ordovician, and sometimes Silurian age. The veins, which vary from 2 to 3 inches in width, but are frequently only ½-inch wide, are usually divided into two parts by a thin seam of iron ore, generally magnetite.

O. B. Hopkins[2] describes the asbestos deposits of Georgia. Asbestos occurs in the State in three varieties: chrysolite, amphibole, and mass-fibre anthophyllite types, 90 per cent. of the rock quarried in Georgia being of the latter type. The value of the fibre, occurring as it does, is three times as great as that of the Canadian chrysolite variety. Mining in Georgia is carried out almost entirely by open cuts and quarrying.

Silicidized Carbon-Silfrax.—F. J. Tone[3] describes a new material to which this name has been given. It differs from ordinary carborundum in important particulars, although still being a silicon carbide. It possesses superior toughness and mechanical strength, a low coefficient of expansion, a high thermal conductivity, and has all the chemical and heat-resisting properties of carborundum, and greater density.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2267–2274.

[2] *Ibid.*, pp. 2275–2284.

[3] Paper read before the American Electro-chemical Society; *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 710–712.

FUEL.

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I.—*CALORIFIC VALUE.*

Calorimetry.—C. Hering[1] discusses the mode of ascertaining the amount of energy required to vaporise carbon, usually called "latent heat" of carbon. In analysing the energy reactions in an electric furnace it is often very desirable to ascertain this factor, which does not appear to have been determined experimentally. It is necessary, likewise, to distinguish between purely physical and purely chemical energy of vaporisation. A table is given showing various factors, including the combustion energy per gramme-molecule of the chief gaseous hydrocarbons.

C. W. Waidner[2] and E. F. Mueller give the results of their investigation of the accuracy attainable with the leading types of calorimeters used for gas-testing purposes. They also indicate the sources of error to which they are liable, and suggest precautions to be observed in their use. The calorimeters investigated were the Junkers (original type), Junkers (new type), Hinman-Junkers, Sargent, Simmance-Abady (English and American types), Boys, Doherty, and Parr.

H. C. Dickinson[3] and N. S. Osborne describe an aneroid calorimeter, that is a calorimeter in which equalisation of temperature is secured by means of the thermal conductivity of copper instead of by the convection of a stirred liquid.

H. Strache[4] and E. Glaser describe a simple and exact method for carrying out heat-value determinations with the Junkers calorimeter, by which the correction of the gas readings is obviated.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 526–528.

[2] *United States Bureau of Standards; Technical Paper* No. 36.

[3] *United States Bureau of Standards; Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 492–493.

[4] *Journal für Gasbeleuchtung*, 1915, pp. 85–88, 97–101.

A new form of recording instrument, the Hinman-Junkers calorimeter, fitted with a pair of special recording thermometers, is described by C. H. Stone[1] and W. H. Hinman.

E. Heer[2] describes a recording calorimeter for registering continuously the calorific value of gases in metallurgical works.

G. N. Huntly[3] deals with corrections in bomb calorimetry.

Pyrometry.—G. K. Burgess[4] and P. D. Foote in dealing with the characteristics of radiation pyrometers give an account of the principles which form the basis for the operation of total radiation pyrometers, and describe representative types of this instrument together with the results of experimental study of their calibration and behaviour under various conditions of use and as modified by changing the several factors which may influence the readings of such pyrometers.

C. R. Darling[5] gives an account of the chief advances made in pyrometry since 1910. During the period under review, no pyrometers based upon new principles have been introduced, the advances made relating to methods previously in use, which are separately considered.

C. C. Paterson[6] and B. P. Dudding describe preliminary experiments on the estimation of high temperatures by the method of colour identity. The temperature of incandescent substances is estimated with very fair accuracy by matching their colour with that of incandescent filament lamps working at appropriate efficiencies. These have previously been calibrated by comparison with a "black body" over a large temperature range. The comparisons are made in the field of a Lummer-Brodhun photometer, and the method is shown to give the correct result for the melting point of platinum.

W. A. Behrens[7] deals with the principles of the electric pyrometer, its operation, and method of calibration.

The measurement of temperature by electric pyrometers is dealt with,[8] and descriptions are given of resistance and thermocouple pyrometers made by the Leeds and Northrup Company, Philadelphia.

Tests of Fuel.—Combustion tests of the various principal types of coal used in the United States have been carried out in boiler furnaces by J. K. Clement,[9] J. C. W. Frazer, and C. E. Augustine.

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[1] Paper read before the American Gas Institute; *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 678.

[2] *Glückauf*, 1914, vol. l. pp. 1603–1604.

[3] *Analyst*, 1915, vol. xl. pp. 41–48.

[4] *United States Bureau of Standards, Scientific Paper; Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 493–495.

[5] *Journal of the Royal Society of Arts*, 1915, vol. lxiii. pp. 590–607.

[6] Paper read before the Physical Society; *Mechanical Engineer*, 1915, vol. xliii. p. 264.

[7] *American Machinist*, 1914, vol. xli. pp. 629–631.

[8] *Ibid.*, 1915, vol. xlii. pp. 317–321.

[9] *United States Bureau of Mines*, 1914; *Technical Paper* No. 63.

The report embodies the results of a series of twenty-three tests with Pocahontas coal.

Utilisation of Low-Grade Fuel.—R. H. Fernald[1] discusses the means of obtaining power from low-grade coal as cheaply as steam power from high-grade coal.

Purchase of Fuel by Specification.—F. R. Wadleigh[2] continues his discussion on the purchase of coal on specification. He studies in detail the effects of sulphur on the actual value of the coal to the consumer. The importance of designating specific sizes is also shown. Two samples of typical specifications are given, one being for the standard proximate method now so commonly used, and the other a more exhaustive and comprehensive type.

Some coal specifications and proposals have been issued by the United States Bureau of Mines,[3] typical of those in use by the United States Government for the purchase of coal under specifications based on the heating value, content of ash and moisture, and other considerations.

Clinkering of Coal.—L. S. Marks[4] deals with the clinkering of coal.

II.—*COAL.*

Origin of Coal.—J. Lomas[5] discusses the formation of coal seams in the light of recent microscopic investigations, and its influence on modern mining practice. He states that most coal seams were originated by a regular deposition from the growth of vegetation on the spot where they were now found, and not, as often believed, by the deposition of vegetable matter in water which had then drifted from other places to where it was now found in the form of coal. Every coal seam so far examined by the author showed that it had been laid down in laminæ or layers which had a natural or orderly sequence, and from these layers it was possible to tell the character of the plants from which the debris had been derived.

D. White[6] discusses the relations of the origin of coal to that of petroleum.

Geology of Coal.—R. J. Sampson[7] deals with the geology of the Harlan coal-field region in South-eastern Kentucky, and describes the coal.

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[1] Paper read before the Cleveland Engineering Society, U.S.A., February 10, 1915; *Colliery Engineer*, 1914–15, vol. xxxv. pp. 415–417.

[2] *Coal Age*, 1914, vol. vi. pp. 580–582, 667–671.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 746–748.

[4] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 205–214.

[5] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 46–48.

[6] *Journal of the Washington Academy of Sciences*, 1915, vol. v. pp. 189–212.

[7] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 371–374.

F. Schmidt[1] discusses the conformation and geological character of the Campine coal-field, Belgium, and its relations with other coal-fields in Western Europe. The main features of the deposits and their tectonic distribution are compared with those of the neighbouring coal-fields of Northern France and South-western Germany.

The geology of the Gard coal-field is similarly dealt with by J. B. Marsaut.[2]

Composition of Coal.—E. Terres[3] discusses the nature of the compounds of nitrogen in coal and coke.

Chlorine in Coal.—A. De Waele[4] describes how an examination of corroded tubes of an economiser revealed an abundance of ferric chloride, which indicated the presence of chlorine in some form in the furnace gases. Samples of the coal used were analysed, and it was found that chlorine was present as soluble chloride, the maximum percentage being 0·346. Without exception the coal used had been mined in the brine districts of the Midlands.

Analyses of American Coals.—A. C. Fieldner,[5] H. I. Smith, A. H. Fay, and S. Sanford present analyses and descriptions of samples of coal collected from many mines throughout the United States. A brief summary is given of the analytical methods used.

Oxidation of Coal.—H. C. Porter[6] and O. C. Ralston discuss the oxidation of coal in connection with the mining and utilisation of the fuel. The rate of oxidation during the period preceding ignition is no doubt one of the factors determining the ease of ignition.

Coal in England.—A short account is published[7] of the progress in the sinking operations at the Harworth Colliery, near Doncaster. The Northern Union Mining Company, Limited, was formed early in 1914 to acquire a coal-field of 15,000 to 20,000 acres at Harworth, the bulk of the capital being German and the board including two of the largest coal-owners in Germany. It is estimated that 750 million tons lie within the area. Most of the workers employed in sinking the shaft were Germans, who had to leave on the outbreak of war, and the work is at a standstill. There were to be two winding engines to each shaft, and the cages were to be raised and lowered independently of each other.

E. B. Lichtenberg[8] describes the Kent coal-field, the proved area of which is approximately 100 square miles, with a probable extension of 50 square miles. The principal collieries already at work are the Tilmanstone, the Snowdown, the Shakespeare, and the Stonewall, and a short description of their equipment is given, together with analyses of the coal obtained.

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[1] *Bulletin de la Société de l'Industrie Minérale*, 1914, Series V., vol. vi. pp. 167–259.
[2] *Ibid.*, vol. v. pp. 337–413.
[3] *Chemiker Zeitung*, 1915, vol. xxxix. p. 73.
[4] *Analyst*, 1915, vol. xl. pp. 146–147.
[5] *United States Bureau of Mines*, 1914; *Bulletin* No. 85.
[6] *Ibid.*, *Technical Paper* No. 65.
[7] *Engineer*, 1914, vol. cxviii. p. 445.
[8] *Mining Magazine*, 1914, vol. xi. pp. 305–312.

Coal in Wales.—A description is given[1] of the geology of the country around Haverfordwest, including the eastern part of the Pembrokeshire anthracite district. These coal measures are described in detail and the character of the faulting explained.

Coal in Belgium.—Some particulars of the production of coal in Belgium, its qualities, and the methods of mining are published.[2] The statistics are accompanied by charts.

Coal in France.—The Alpine coal-field south of Geneva, in South-eastern France, which subtends parts of Southern Switzerland and Northern Italy, is described by F. Laur,[3] who discusses the geology of the region and its correlation with adjacent Alpine areas. A number of thin seams of anthracite occur in the coal-field, some of which are worked while others have been worked in the past. An anthracitic-graphite deposit of curious nature is also met with.

Coal in Russia.—J. W. Revillon[4] describes the growth of the coal industry of South Russia. The coal-producing area is essentially the Donetz Basin, which contains every variety of coal from anthracite to lignite, of excellent quality. It was not till 1840, however, at Grousheffka, that coal, in the shape of anthracite, was first really worked, although its existence in the district had been known for many years. The coal-field covers a very large area, included within the following points: Lisichansk in the north-west, Elenoffka in the south-west, Grachi in the north-east, and Alexandra Grousheffka in the south-east. The seams worked are very numerous; they vary in thickness from about 7 feet to 2 feet, and in nature from anthracite in the east to nearly bituminous coals in the north-west.

C. R. King[5] describes the coal resources of South Russia. The Donetz Basin is one of the principal coal-fields of the world, containing practically inexhaustible supplies of anthracite and bituminous coal.

B. Simmersbach[6] gives an account of the coal-mining developments in South Russia.

Coal in Iceland.—On account of the scarcity of coal in Denmark,[7] the coal deposits of Dufansdale in Iceland have been examined, with encouraging results. The deposits appear to be extensive and the quality is satisfactory, and improves at greater depths. They are situated upon a firth with excellent anchorage for vessels.

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[1] *England and Wales Geological Survey*, 1914; *Memoir* No. 228.

[2] *Colliery Guardian*, 1914, vol. cviii. pp. 515–517.

[3] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 387–401.

[4] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 245–246.

[5] *Engineering Magazine*, 1914–15, vol. xlviii. pp. 481–492.

[6] *Oesterreichische Zeitschrift*, 1914, vol. lxii. pp. 644–649.

[7] *Journal of Industrial and Engineering Chemistry*, 1915, vol. vii. p. 75.

Coal in Spitzbergen.—According to K. Bay[1] the mineral resources of Spitzbergen have of late years attracted considerable attention. Extensive coal deposits are found in the tertiary formations in an area covering nearly five square miles. Between Green Harbour and Advent Bay they are estimated to contain about 1000 million tons. Other coal deposits have also been found at King's Bay consisting of pure coal without any intervening strata, the thickness being 5 feet. The heating capacity of the coal is 12,000 British thermal units, and on account of its low percentage of ash it is excellent steam coal. The working is very easy, there being no water in the mines on account of the frozen ground. There is no development of gas and the temperature keeps at about 2° C. below freezing-point throughout the year. The Arctic Coal Company shipped 40,000 tons, mostly to Norway, in 1912 and 1913.

Coal in India.—L. L. Fermor[2] describes the geology and coal resources of Korea State, Central Provinces. Coal of good quality exists in both the Sanhat and Kurasia fields. The Sanhat has an area of about 330 square miles, and the exposures indicate the existence of considerable quantities of coal in this area. The Kurasia is the second of the Korean coal-fields in point of size, having an area of about 48 square miles. In the Chirmiri area of this field, the finest series of coal-seams in the State is exposed in the Kaoria Nala. Seven seams of an aggregate thickness of 36 feet were measured, the analyses showing the following composition:—

	Per Cent.
Moisture	6·24 to 9·08
Volatile matter	23·48 to 33·86
Fixed carbon	48·08 to 54·20
Ash	5·50 to 16·72

Coal in Burma.—G. de P. Cotter[3] describes some newly discovered coal-seams near the Yaw River, Pakokku district, Upper Burma.

Coal in China.—M. B. Yung[4] deals with the coal deposits of the Fu Chuan district, which lies near the eastern boundary of Kwang Si province in Southern China, and has river connections with the coast. On the Yuen River a fine quality of coking coal is being mined. Three seams, aggregating 24 feet in thickness, occur in a black shale bed, in limestone. The composition of the coal is as follows:—

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[1] *Engineering*, 1914, vol. xcviii. pp. 760–761.
[2] *Memoirs of the Geological Survey of India*, 1914, vol. xli. pp. 148–245.
[3] *Records of the Geological Survey of India*, 1914, vol. xliv. pp. 163–185.
[4] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2451–2458.

	Per Cent.
Moisture	1·2
Volatile matter	18·5
Carbon	65·0
Sulphur	0·9
Ash	14·4

The coke yield is 71 per cent.

The coal resources of the Chan-Si province, Northern China, are described by Bordeaux.[1] Anthracite of high quality and hardness occurs, while further south excellent bituminous coal is found. The coal-fields of Chan-Si exceed greatly in area the extent of the British coal-fields, taken altogether, and the anthracite is only inferior to Welsh sorts in respect of its higher ash contents.

Coal in East Africa.—A description is given[2] of the economic resources of German East Africa. Coal-beds are contained in the Karoo strata which occur in various parts of the plateau highlands, notably in the area surrounding the northern portion of Lake Nyasa. Many of these beds are thin, and consist of coal of poor quality, as, for example, those near the mouth of the Ruhuhu on the east side of Lake Nyasa. More important than these Ruhuhu deposits, however, are those in the Karoo beds to the north-west of the Lake, on the Songue and Kivira rivers. In this area a section in the Kandete stream shows a thickness of 11 metres of coal in a total thickness of 20·7 metres. One portion of this section shows a seam of coal 4·90 metres thick, with two thin shale partings, which together have a thickness of only 6 centimetres. The average composition of the coal of this 4·9 metres seam is as follows:—

	Per Cent.
Carbon	60·6
Hydrogen	3·0
Oxygen	13·0
Sulphur	0·25
Moisture	4·33
Ash	18·50

The yield of coke was 78·70 per cent., and the calorific value 5657 calories. Certain of the seams show a higher percentage of carbon, up to 70 per cent., and a calorific value of 6840 calories. The ash in some samples falls as low as 5 per cent. The coal is of the bituminous type, and on account of its coking properties could be used for smelting iron ores.

Coal in United States.—The Book Cliffs coal-field, Utah, is described by R. S. Lewis.[3] The coal-field is situated in Sevier county, and the coal-beds outcrop in escarpments along a valley, and are more extensively worked than any other in the State. The bedding is massive sandstone intermixed with sandy shales, beds of coal, and carbonaceous shale. The coal is bituminous and of high grade, with the property of resisting weather to a marked extent. Its calorific value ranges from 13,480 to 14,750 British thermal units. The seams worked range from 5 to over 20 feet in thickness, and are remarkably free from impurities. Considerable areas of burned coal are encountered.

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[1] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 4–10.
[2] *Bulletin of the Imperial Institute*, 1914, vol. xii. pp. 580–599.
[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 1729–1749.

The methods of working are fully described, and analyses are given of the prevailing types of coal found in different localities within the coal-field. The following analyses show the nature of the coals in question:—

Analyses of Utah Coal.

Locality.	Moisture per Cent.	Carbon, Fixed, per Cent.	Carbon, Volatile, per Cent.	Ash per Cent.
Castle Valley .	2·16	47·56	44·60	5·64
Black Hawk .	2·14	47·29	43·53	7·04
Hiawatha . .	3·29	51·22	40·98	4·51
Castle Gate .	2·88	54·41	39·57	3·14
Sunnyside. .	1·87	54·78	39·22	4·13

The sulphur in the last two examples is given as 0·493 and 1·022 per cent. respectively.

W. R. Crane[1] describes the occurrence of lignite in Cook Inlet and Kachemak Bay region, Alaska. In general the coal-beds are not of great thickness, averaging close to 24 inches, although many 6 to 8 feet beds are to be found; the larger number do not, however, exceed 20 inches. There are numerous bands of shale, clay, and sandstone in the coal-beds, which will in places render of little value what would otherwise be remarkably good and workable beds.

A list is given[2] of the workable coal-seams of Western Pennsylvania, together with their thicknesses, and approximate analysis.

H. A. Kuhn[3] discusses the coal resources and coal-mining practice of Western Pennsylvania. The field is the most important in the world, and is the basis of the great iron industry of Pittsburg. The quality of the coal is wonderfully uniform throughout the whole field, and when it differs it does so in ways so fully known that it is possible to predict the tonnage and composition of the deposits found in any particular area. It thins and becomes less pure as it extends westward. The deposits are, however, within measurable distance of exhaustion.

Coal in Mexico.—According to E. O. Forster Brown,[4] the coal production of Mexico is practically all obtained from collieries in the

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[1] *Mining and Engineering World*, 1915, vol. xlii. pp. 209–213.
[2] *Colliery Engineer*, 1914–15, vol. xxxv. p. 297.
[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2586–2605.
[4] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 381–421.

State of Coahuila, within 100 miles of the border of the United States. There are no authoritative statistics of the native production, or of the total coal or coke consumption in the Republic. The major portion of the output is obtained from the Sabinas Basin, which has a maximum length of about 29¾ miles and a maximum width of about 12½ miles. The coal in this basin is bituminous, while the percentage of actual ash is high, altogether apart from the high percentage of mechanically intermixed impurities. A satisfactory coke is produced from the small, and the larger sizes of coal are used for steaming purposes. The Saltillito-Lampacitos Basin comes next in importance. The analysis of the coal at Lampacitos Colliery, as regards ash content, varies considerably in different parts of the workings; compared with the Sabinas Basin coal, however, the untreated mine-run coal generally contains less ash, and always less volatile matter and more fixed carbon. The seam at Rio Escondido, in common with those in the other districts, varies greatly in thickness, from a minimum of 2 to a maximum of 5 feet, with one or two thin dirt bands. The coal is much harder than the Sabinas coal, it has a cubical fracture, and the ash is largely inherent. The coal will not coke, and is used mainly in gas-producers and locomotives on railways where a free-burning coal is required.

Coal in Victoria.—H. Herman[1] gives an account of the coal resources of Victoria. Bituminous coal of Jurassic age occurs at various places in the southern portion of the State in three main areas, the Wannon, Otway, and South Gippsland. The South Gippsland area occupies about 2100 square miles. Of greater extent than the bituminous coal deposits are the deposits of brown-coal, which are probably the thickest in the world. At Morwell 780 feet of coal was passed through in a bore 1010 feet deep. It is estimated that Victoria contains not less than 30,000 million tons of brown-coal.

Coal in Western Australia.—H. P. Woodward[2] gives an account of the boring for coal upon the Murchison Railway line between Eradu and Mullewa. A bore hole, which was put down in 1906 near Eradu, commenced to cut thin coal-seams at a depth of 100 feet and at 118 feet encountered a six-foot seam of weathered coal, shaly in part. Samples from this seam were tested, and the following results were obtained :—

	Per Cent.
Moisture	9·59
Volatile hydrocarbons	40·28
Fixed carbon	37·97
White ash	12·16

The coal had a calorific value of 9,900 British thermal units.

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[1] *Victoria Geological Survey*, 1914, *Bulletin* No. 34.

[2] *Western Australia Geological Survey*, 1914, *Bulletin* No. 59, *Miscellaneous Report* No. 33, pp. 9–12.

Charcoal.—The economic aspects of the hardwood distillation industry of the United States are discussed by E. H. French[1] and J. R. Withrow. The construction of the ovens is described. The yield by the best and most approved modern methods is from 22 to 25 gallons of tar per cord of wood used (8″ × 4″ × 52″), and about 1040 pounds of charcoal; 215 to 220 gallons of crude pyroligneous distillate and 11,000 to 12,000 cubic feet of gases are also obtained per cord, the average price of the wood varying, but seldom exceeding 20s. and that of the products aggregating about £2. Greater profits could be realised by manufacturing the higher class of finished products at plants making the crude ones.

R. C. Palmer[2] discusses the establishment of a hardwood distillation industry on the Pacific Coast. The yield of charcoal, alcohol, and acetate is considerably higher from hard woods than from soft, and if carried out in the places where such hardwoods occur would save freights. Birches, maples, and oaks are available, there being no less than fifteen varieties of the latter, as well as eucalyptus, acacias, madrone, &c. The woods chiefly available for such an industry are the tanbark oak (*Quercus densiflora*) and the Californian oak (*Quercus Californica*) or beach oak. A cord, or 90 cubic feet of these woods, will yield about 1050 pounds of charcoal and over 200 pounds of acetate, together with about 11½ gallons of crude alcohol. The small limbs yield more than the large timber. Actual tests have given the following figures:—

	Crude 82 per Cent. Alcohol.	Grey Acetate of Lime.	Charcoal, Lbs.
Black oak . . .	8·7	147	1140
White oak . . .	8·7	135	1090

which show substantially lower yields than the figures previously given, which refer to laboratory trials. With charcoal at £2 per ton, the value of the crude products per cord comes to between about £2, 2s. and £2, 6s.

It is stated[3] that in some recent charcoal-burning operations in the Forest of Dean a yield of about 20 per cent. of charcoal was obtained from oak. The expenses of burning vary between 18s. and 25s., and the cost of the wood is about 15s. per ton of charcoal obtained, in addition to which there is the cost of sacks and cartage. In normal circumstances the charcoal sells at 40s. to 50s. per ton in large consignments, though at the present time as much as 70s. to 80s. is being obtained.

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[1] Paper read before the American Institute of Chemical Engineers, December 4, 1914; *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 30–39.

[2] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 623–626.

[3] *Journal of the Board of Agriculture*, 1915, vol. xxi. pp. 1032–1037.

O. Tingberg[1] furnishes particulars of the trials undertaken at Domnarfvet with Ljungberg's system of charcoal burning. This differs from the ordinary system in having a small furnace outside the pile, instead of firing direct in the centre of the latter, and leading the heated gases into circular flues built up into the pile. The whole system of flues was provided with dampers, and condensers for the by-products. Although this arrangement gave a vastly better result than the ordinary pile, it was about on an average with the best types of the newer kind of kilns. By discarding the flues, but still using the outside furnace and, further, forming a conical bottom of loose, large pieces, there was obtained as high a percentage as 81·23 of the whole wood used.

H. Aminoff[2] furnishes a description and working figures of a Marks' patent charcoal kiln. This is really a continuous process, and consists of a long brick tunnel through which the loaded waggons are passed. Locks are provided at each end to prevent loss of heat when forwarding the waggons. Each waggon holds $10m^3$ of cut wood, and 11 to 17 waggons pass through during the day, according to the state of moisture in the wood; 16 waggons are in the kiln at any one time. The heated gases are delivered at a temperature of 500°, and on their passage down the tunnel are reduced to 90° to 100°. They are then led through a cooling tower where the tar, &c. is deposited. The latter is of excellent quality and can be barrelled direct. The kiln treats about $25,000m^3$ of wood per annum and costs about £4500.

Peat.—It is stated[3] that peat fuel is made in Holland from two kinds of ground, the sphagnum peat beds being found on the moorlands, while the sedge and grass peat beds are situated in marshy bogs. Machines are very little used in the preparation of short peat. In the peat bogs of North Holland machines are here and there used for pulping and kneading. In some peat fields, the upper layer of peat to a depth of one-half to one-and-a-half yards is of a light brown colour. This peat is very porous and light in weight. From this sort of peat, "bolsterturf" peat dust is produced. The yearly production of peat dust in Holland amounts to 200,000 tons.

B. F. Haanel[4] describes in detail the methods of manufacturing peat fuel, and lays stress on the problems encountered in removing by pressure or by means of artificial heat the contained water.

C. Blacher[5] and W. Duglas discuss the necessity of establishing the peat fuel industry on a scientific basis. A classification of peats according to their composition is presented.

A. J. Forward[6] discusses the commercial uses for peat.

[1] *Bihang till Jernkontorets Annaler*, 1914, pp. 207-220.
[2] *Ibid.*, pp. 95–100.
[3] *Canadian Mining Journal*, 1914, vol. xxxv. pp. 746–747.
[4] *Canada, Department of Mines, Mines Branch*, 1914, *Report* No. 299.
[5] *Feuerungstechnik*, 1914, vol. ii. pp. 321-325, 342–344.
[6] *Canadian Mining Journal*, 1914, vol. xxxv. pp. 743–744.

III.—*COKE.*

Coke-Oven Practice.—J. W. Lee,[1] in his Presidential Address to the Yorkshire Junior Gas Association, deals with the chemistry of coke-oven operation, and describes the working of a battery of 110 Otto by-product ovens.

T. B. Williams[2] describes coke-oven practice in Western Canada. There are over 1900 coke-ovens in Alberta and British Columbia, and of these all except fifty are beehive in principle.

By-Product Coke-Ovens.—An illustrated description is given[3] of the coking and by-product recovery plant at the Coedely Colliery. The ovens are of the Coppée regenerative type, and are in two batteries of thirty. Each battery is served by an independent electrically-driven coal-compressor, together with a Buchanan coke ram and discharging machine; but any one unit can be made to serve either or both batteries. Provision is also made for charging the ovens from the top in case of emergency. The capacity of each oven is 10 tons, and the time of coking is approximately thirty-two hours.

The new coking and by-product plant at the Newport works of Sir B. Samuelson & Co., Middlesbrough, is described[4] and illustrated. There are 46 Otto regenerative ovens, each having a capacity of over 9 tons of coal, which is carbonised in about twenty-eight hours.

The new coking plant of the Team By-Product Coke Company, Dunston-on-Tyne, is described and illustrated.[5] There are 120 Otto regenerative ovens, with recovery plant for benzol, sulphate, naphthalene, and a tar-distillation plant. The ovens, which are arranged in two batteries, are approximately 33 feet 7 inches long by 7 feet 11 inches high, with a main width of 1 foot 9 inches. Each oven has a capacity of 8½ tons of washed coal, the time required for coking being about twenty-eight hours.

H. Groeck[6] gives an illustrated description of the coke-oven installation of the Collin type lately put into operation at the Radbod collieries. The battery consists of eighty ovens, with chambers 11 feet in height.

Beehive Coke-Ovens.—Improvements in beehive coke-ovens are dealt with,[7] the McMurray door, the Stauft coke extractor, and Campbell's plastic clay for filling and daubing coke-oven doors being described.

Coke-Oven Statistics.—It is stated[8] that the total number of coke-making plants in France in 1912 was 38 and the number of ovens

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 334–335.

[2] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 429–465.

[3] *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 693–695.

[4] *Ibid.*, p. 795.

[5] *Ibid.*, 1915, vol. xc. pp. 633–635.

[6] *Zeitschrift des Vereines deutscher Ingenieure*, 1915, vol. lix. pp. 195–197.

[7] *Connellsville Courier; Colliery Engineer*, 1914–15, vol. xxxv. pp. 247–248.

[8] *Iron and Coal Trades Review*, 1915, vol. xc. p. 641.

3885, of which 2340 were operated with by-product recovery and 1545 without. In that year the production of coke was 3,667,393 tons, of which 2,690,252 was by-product.

Coke-Ovens heated with Blast-Furnace Gas.—O. Simmersbach[1] gives full details of two tests carried out on the heating of coke-ovens by blast-furnace gas. The principal advantages are that a greater uniformity of temperature in coke mass can be preserved and the coking time is reduced, notwithstanding the low calorific value of the gas. The ovens used for the experiments were Koppers' compound ovens, 10 metres long, 2·6 metres high, and 0·5 metre average width. Elaborate calculations of the heat-balance are made.

Manufacture of By-Product Coke.—G. S. Cooper[2] deals with the manufacture of by-product coke in Scotland. By-product coking has not developed in Scotland to the same extent as in the north of England. This is owing to the fact that splint coal is largely used in the blast-furnaces and that much of the coal as mined at present offers certain difficulties to its treatment in by-product ovens. The author has examined a number of coals from various parts of Scotland, and estimates the probable yield of coke to be about 65 per cent.; sulphate of ammonia, 1·5 to 1·7 per cent.; tar, 4 to 6 per cent.; and crude benzol, about 3 gallons per ton of coal.

The majority of Scottish coals contain from 30 to 35 per cent. of volatile matter, and if carbonised in the ordinary way the coke produced would be too soft and spongy for metallurgical purposes.

The author devotes considerable space to a description of the Koppers' ovens installed at the Saltley Gasworks of the Birmingham Corporation, where the whole of the gas produced is employed for town purposes, whilst the metallurgical coke produced is disposed of to works in the neighbourhood.

T. G. Watts[3] deals with the development of the by-product coke-oven in South Wales, and points out that its adoption has been slow, due largely to the low volatile matter in the coal of that district. He gives the following table showing the by-product yields per ton of coal carbonised:—

By-Products.	South Wales.	Yorkshire.	Average, United Kingdom.
60 per cent. benzol .	1 to 1½ gallons	2½ to 3 gallons.	2½ gallons.
Tar	56 to 68 lbs.	112 lbs.	89½ gallons.
Sulphate of ammonia	18 to 20 lbs.	22 to 35 lbs.	24 lbs.
Gas	8,000 to 10,000 cub. ft.	10,000 to 11,000 cub. ft.	10,000 cub. ft.

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1498–1503, 1552–1556, &c.

[2] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlviii. pp. 427–439.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 606.

There are about 690 by-product ovens in the Welsh coal-field.

The various stages in the manufacture of by-product coke and descriptions of several of the leading types of by-product recovery coke-ovens are dealt with by H. C. Estep.[1]

E. B. Wilson [2] discusses the adaptability of West Virginia coals to by-product coking.

F. C. Lucas[3] deals with the distillation of coal and the recovery of by-products.

Recovery of By-Products.—A description is given[4] of the gas-tar distillation plant at the Saltley Gasworks, Birmingham. The plant is designed to deal with the tar from a 90-ton battery of Mond producers which supply gas for coking the charges in a battery of sixty-six Koppers' ovens.

W. Diamond[5] describes methods for the recovery of benzol from coal-gas.

The manufacture of cyanides from coal-gas is dealt with by C. C. Tutwiler,[6] who describes the Knublauch, Feld, Bulb, "British Cyanide," and Stavorinus processes.

Ammonium Sulphate from Peat.—U. Rossi[7] deals with the production of ammonium sulphate from peat in Italy.

Coke-Oven Equipment.—Amongst recent improvements in the equipment of coking ovens are the McMurray door for rectangular ovens, which is lined with a plastic clay daubing mixture and has proved satisfactory, and a mechanical door extractor which consists of a jack on a truck, run out ahead of the coke machine. The door is mechanically swung out and then placed on supports at either side of the oven door. Both these contrivances are described and illustrated.[8]

Coke-Oven Accessories.—An illustrated description is given[9] of a machine, devised by J. J. Allen, for cleaning the pipes in by-product coke-ovens. A machine of this type has been successfully operated at the Bankfoot plant of Pease & Partners, and it is claimed that the coking time has been reduced from thirty-two to twenty-eight hours.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 1171–1178, 1196*b*.

[2] Paper read before the West Virginia Coal Mining Institute; *Colliery Engineer*, 1914–15, vol. xxxv. pp. 151–153.

[3] Paper read before the Mining Society of Nova Scotia; *Canadian Mining Journal*, 1915, vol. xxxvi. pp. 13–15.

[4] *Iron and Coal Trades Review*, 1915, vol. xc. p. 568.

[5] Paper read before the North of England Gas Managers' Association, May 1, 1915; *Iron and Coal Trades Review*, 1914, vol. xc. pp. 638–639.

[6] *Journal of the Franklin Institute*, 1914, vol. clxxviii. pp. 383–415.

[7] *Monthly Bulletin of Agricultural Intelligence*, Rome; *Journal of the Royal Society of Arts*, 1915, vol. lxiii. pp. 162–163.

[8] *Iron Trade Review*, 1914, vol. lv. pp. 525–526.

[9] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 774–775.

A. Thau[1] illustrates and describes a mill for crushing coking coal. The apparatus is in operation at Llwynypia in Wales.

R. E. Gibson[2] compares the efficiencies and costs of various mechanical systems of transporting coke.

Cleaning Coke-Oven Gases.—W. Strommenger[3] gives an account of an apparatus for the removal of naphthalene from coke-oven gas. The washing medium is a heavy oil, anthracene oil being used in the particular case described by the author. The gas is blown in finely divided streams through a bath of this oil, and surface condensation of the naphthalene takes place. The principle of the apparatus depends on the superior capacity of the oil over the gas to absorb the naphthalene. Such a washing plant has been in successful operation at the Phœnix Works in the Ruhr district for over twelve months.

By-Products Industry.—The coal-tar colour industry of the United States is dealt with by I. F. Stone.[4] Scepticism has existed in regard to the existence of the industry and the nature and quality of its products, which has been carefully fostered by European, and particularly by German manufacturers. The war, however, by diminishing the exports of German dye-stuffs to America, has both served to reveal the existence of an American industry and has stimulated its activity. A sketch is given of the progress of discovery of the aniline and other dyes, and it is shown that the prospects of the United States dye industry are exceptionally promising, as in no other country in the world are the raw materials so plentiful and so readily available.

The full text of the report of the Chemical and Dye-stuff Committee of the New York Section of the American Chemical Society has been published.[5] It contains a review of the conditions of the industry concerned in the United States and data relative to the availability of raw materials for coal-tar industry and to the products to be derived from it. The report suggests that the so-called tar "intermediates" should be assessed for fiscal purposes at one-half of whatever the finished products are taxed.

At a recent meeting of the American Gas Institute the following papers, of which abstracts have been compiled,[6] were presented:—"Coal Gas Residuals," by F. H. Wagner; on the electrical separation of tar from coal-gas, by W. W. Steere,[7] who deals with his own process and compares it with the results of the Cottrell process; and a general paper on "Gas Manufacture from the point of view of Chemical Industry," by W. F. Rittman. The paper on coal-gas residuals is given *in extenso*,[8] the residuals dealt with being the tar, naphthalene, cyanogen, ammonia, and benzol. The principles underlying the separation of the chief by-products are discussed, with special reference to the application of the Feld hot tar washer and to the Feld processes used in conjunction with a Pelouze condenser for the recovery of the chief residuals. A diagram is given of a complete plant for the extraction of ammonia and hydrogen sulphide and the production of ammonium sulphate.

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[1] *Glückauf*, 1914, vol. l. pp. 1560–1563.

[2] Paper read before the Manchester District Institution of Gas Engineers, February 27, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. p. 365.

[3] *Glückauf*, 1915, vol. li. pp. 138–141.

[4] Paper read before the American Chemical Society; *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 679–684.

[5] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 753–756.

[6] *Ibid.*, pp. 677–678. [7] *Ibid.*, pp. 775–778. [8] *Ibid.*, pp. 696–702.

Coke-Oven Gas for Town Lighting.—For some time a scheme has been in successful operation for supplying Middlesbrough with coke-oven gas for town-lighting purposes.[1] The ovens in use are of the ordinary regenerative type, and being heated by coke-oven gas only about half the total amount of gas is available for town purposes. Several firms of coke-oven builders have designed another type of oven which is especially suitable for the production of the largest possible amount of surplus gas; such ovens are heated either by blast-furnace gas or by producer-gas, thereby leaving the whole of the coal-gas available for town purposes. Where producer-gas is employed, by-product recovery from the producer-gas can also be incorporated, and by using a good class of fuel a very handsome return can be obtained from the by-products. Ovens of this type have been at work for some time at one of the gasworks of the Birmingham Corporation.

IV.—*LIQUID FUEL.*

Origin of Petroleum.—J. Chautard[2] has made a number of researches on the problem of the origin of petroleum. He concludes that while geology does not supply any general evidence of the inorganic origin of petroleum, it furnishes powerful facts in favour of the theory of its organic origin, and generally speaking allows of the deduction that every known oil deposit has arisen from organic debris deposited in lacustrine and, generally, halogenic environments.

J. Chautard[3] discusses the origin of the petroliferous mounds of Texas and Louisiana. The hypotheses put forward to account for their formation are criticised, and it is shown that the mounds have an origin which is independent of orogenic or eruptive action. The processes of formation are held to have been sedimentation in an intermittent lagoon followed by a hydrocarbon decomposition of the organic debris, the transformation of the anhydrite into gypsum with resulting compression and the migration of the petroleum under the influence of the pressure on the mother rocks.

D. White[4] deals with the origin of petroleum, and notes how some of the fundamental conditions attending the formation of coal and its differentiation in kinds may similarly apply to oil.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 147.
[2] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 457–460.
[3] *Ibid.*, 1915, vol. clx. pp. 69–72.
[4] *Journal of the Washington Academy of Sciences*, 1915, vol. v. pp. 189–212.

C. W. Washburne[1] discusses the capillary concentration of gas and oil in connection with theories relating to their origin and modes of formation. The capillary constants of the paraffin series are given, together with a short table of approximate maximum capillary pressures in bores of small constant diameter and at different pressures and depths. The rôle of capillarity in producing anticlinal distribution of oil requires consideration. Capillary concentration is an essential requirement of organic theories of the origin of oil, but is not an essential in inorganic origin theories.

E. Coste[2] compares the arguments in favour of the rock disturbance theory of petroleum emanations with those in favour of the anticlinal or structural theory of petroleum accumulations. The physical facts and the known geological factors are summarised. The views advanced are criticised and discussed by H. von Höfer.[3]

E. Ordoñez[4] deals with the origin of petroleum, basing his arguments on evidences drawn from the oil-fields of Mexico, which he has made the subject of special investigation and research. He contends that the connection between oil and small volcanic apparatus is exclusively mechanical and has nothing to do with the origin of the oil, which is hypothetically regarded as being of purely organic derivation.

Geology of Petroleum.—Hume[5] deals with the origin and distribution of petroleum as illustrated in Egypt. The geological formations in which petroleum was chiefly found were eocene, miocene, and pleiocene, and it was the miocene formation that was most prevalent in Egypt.

Composition of Petroleum.—A. Gouere[6] reviews the chemical composition, specific gravity, colour, odour, flash and fractional distillation of different crude oils. Tables and curves are given showing the physical characteristics of 5 per cent. fractions of petroleums from Pennsylvania, Campina, Peru, and Danbovitza. Pennsylvania crude oil differs from the others in that the fractions above 310° decrease in specific gravity and flash, with an increase of the boiling point.

F. W. Bushong[7] expresses the conviction that a thorough series of fractional distillations on an industrial scale would open up enormous possibilities for manufacturing chemical products from petroleum. He gives the results of a series of four distillations of typical Oklahoma oils. The composition of several of the fractions was determined by treating with ozone in the cold. The ozone reaction gives a valuable means for detecting new constituents of petroleum, and the extraction method of Edeleanu enables the removal of these constituents from the main body of the petroleum in concentrated form to be effected.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2365–2378.

[2] *Ibid.*, pp. 2415–2427. [3] *Ibid.*, pp. 2428–2431. [4] *Ibid.*, pp. 2531–2535.

[5] Lecture delivered before the Cairo Scientific Society; *Petroleum Review*, 1915, vol. xxxii. p. 396.

[6] *Revue de Chimie Appliquée*, 1914, vol. iii. pp. 90–98.

[7] *Journal of Industrial and Chemical Engineering*, 1914, vol. vi. pp. 888–890.

Petroleum in Italy.—G. Armani[1] and A. G. Rodano describe the character of the mineral oil from the Ripi mines in the province of Rome. It is a thick black liquid, of peculiar garlic-like odour and neutral reaction. The original oil has a viscosity of 18·74 (Engler) at 30° and 2·60 at 70°. It contained considerable quantities of asphaltic substances, was 90 per cent. insoluble in concentrated sulphuric acid, contained 5 per cent. of sulphur and gave 10,135 calories. By repeated treatment with sulphuric acid and hydrate of soda it purifies to a clear canary-coloured liquid, with a heat value of 10,300 calories and 2 per cent. of sulphur.

Oil Shale in Sicily.—G. Ponte[2] states that deposits of bituminous shale occur in various parts of the province of Messina, and are easily accessible without costly excavation. A laboratory test was carried out on 150 kilogrammes of the material which was distilled in an iron retort with the aid of superheated steam at 2 atmospheres pressure, and there were obtained 7·9 per cent. of crude oil having a specific gravity of 0·928 at 15° C., 5 to 6 per cent. of ammoniacal liquor (0·9 to 1 per cent. NH_3), and 3 to 4 per cent. of gas containing only traces of carbon dioxide. The crude oil contained 3·4 per cent. of sulphur and yielded 29 to 31 per cent. of light oil of specific gravity 0·82 and up to 12 per cent. of crude paraffin. If the shale were distilled in Pumpherston retorts, the gas produced would suffice for heating the retorts without any extra fuel. During the purification of the light oil with sulphuric acid, some ichthyolsulphuric acid, soluble in water, was produced.

Petroleum in Russia.—V. Latkin[3] describes the petroliferous deposits of the Ural province, Russia.

K. A. Prokopoff[4] describes his investigation of the petroliferous areas of the Kuban district.

Petroleum in China.—Extracts are given[5] from two letters published in 1829 containing the observations of a missionary named Imbeot on the oil, gas, and brine wells in the province of Sse-Tchuen, China.

It is stated[6] that the best-known petroleum district of China is in Ssu-chuan, and the petroleum resources of Chih-li, Shan-si, Shensi, and Kansu are now being explored and developed. In Ssu-chuan petroleum, gas, and brine, or any one of them, may be found in any given well. When the gas flow is strong the well is capped, and when the gas is unimportant the petroleum and brine are drawn off into reservoirs. The petroleum is of a variety of colours, some milk-white, which is pure enough to burn with a good light; a greenish-white variety, which is less useful; a dark yellow, which is still less useful; and a viscous black variety, which gives little light and much smoke. The Chinese know nothing of the art of refining this petroleum, and burn it just as it is in crude lamps. There are from thirty to forty petroleum wells in the Tze-liu-ching district of Ssu-chuan and about fifty in the whole province.

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[1] *Annali di chimica applicata*, 1914, vol. ii. pp. 74–79.

[2] *Industria chimica mineraria e metallurgica*, 1915, vol. ii. pp. 31–34.

[3] *Journal of Finance, Trade, and Industry; Petroleum Review*, 1915, vol. xxxii. pp. 75–76, 95–96.

[4] *Neftannoie Dielo; Petroleum Review*, 1915, vol. xxxii. p. 190.

[5] *Petroleum Review*, 1915, vol. xxxii. pp. 39–40.

[6] *Ibid.*, p. 14.

K. Kalitzki[1] describes the geological structure of the petroliferous deposits of Boia-Dag, Central Asia.

Petroleum in Persia.—The Anglo-Persian Oil Company's[2] production is at present obtained entirely from the Maidan-i-Naphtun area, and the oil is conveyed 145 miles by pipe line to the refinery at Abadan on the Persian Gulf. The pumping station is situated at Tembi, about 2½ miles from the oil-field. The pipe line is 6 inches in diameter as far as Wais, a distance of 53 miles, and 8 inches thence to Abadan, and has an estimated capacity of about 1000 tons per day. The total storage at the refinery under construction will have a capacity of nearly 110,000 tons, of which 60,000 tons will be for crude oil.

Petroleum in Canada.—E. H. Cunningham Craig,[3] in describing the prospective oil-fields of Western Canada, sets forth the main geological features of the oil, and it is stated that practically all the petroleum discovered there has its origin in the cretaceous formation. Some interesting particulars are given of the developments in the Athabaska district and in the north of Alberta, where geologists have great hopes of proving a paying oil-field.

E. H. Cunningham Craig[4] also describes the oil-fields of Alberta.

R. W. Brock[5] gives some information relating to the strike of oil in the Dingman Well, near Black Diamond, in the Calgary district, Alberta. In this well oil was struck at a depth of 2700 feet, and quickly rose to a height of from 2000 to 2200 feet in the well. The oil is a "white oil" consisting of almost pure gasoline, and can be used in its crude state as a satisfactory motor spirit.

Petroleum in the United States.—A. H. Brooks[6] describes the petroleum fields of Alaska. Seepages are known at four localities all in the Pacific seaboard, namely, Yakataga, Katalla, Iniskin Bay, and Cold Bay. Petroleum residues have also been found near Smith Bay. Reference is made to the bibliography of the geology of the Alaska oil-field. Alaska petroleum, so far as its composition is known, is a refining oil with a paraffin base and low sulphur content. The Katalla oil-field is about 25 miles in length, and from 4 to 8 miles wide. It lies partly in the southern slope of densely timbered highlands, and partly in the flats adjacent to the shore. Drilling has been made at several localities, but productive wells are limited to that part of the belt lying between the town of Katalla and Bering River. The Yakataga field lies 80 miles east of Katalla, and extends about 20 miles in length, and from one-half to two miles from the beach. The district is, however, almost inaccessible owing to glaciation. At Iniskin Bay the petroleum occurs in the sandstone formation, the field being readily accessible from the good harbours lying both north and south. The Cold Bay field is also accessible, but both these latter regions lack timber. Operations in Alaska are very expensive on account of the cost of transportation, and the Alaska oil boom, which reached its zenith in about 1904, has collapsed considerably owing to the rapid increase in the California outputs.

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[1] *Neftannoie Dielo; Petroleum Review*, 1915, vol. xxxii. p. 117.
[2] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 235–238.
[3] *Journal of the Institution of Petroleum Technologists*, 1914–15, vol. i. pp. 127–145.
[4] *Petroleum World; Canadian Mining Journal*, 1915, vol. xxxvi. pp. 26–28.
[5] *Canadian Mining Institute*, 1914, *Bulletin* No. 27.
[6] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 199–207.

The extent and productiveness of the oil-lands of California are outlined,[1] and the cost of drilling wells and recovering the oil is discussed.

R. Arnold[2] and V. R. Garfias describe the general methods employed in Calfornia for recovering the oil, when, owing to insufficient gas pressure or other causes, it does not rise to the surface by natural flow. A description is given of the different pumping devices and means of generating power to operate them, and their relative cost and field of usefulness is summarised.

E. G. Woodruff[3] and D. T. Day describe the distribution and character of the oil shale in North-western Colorado and North-eastern Utah. Bituminous shale occurs in lenticular beds ranging from a fraction of an inch to 80 feet in thickness. The shale does not split or break easily, but separates readily from the associated beds. This is an important factor in the development of an oil-shale industry. The specific gravity of the shale averages 1·60. The average yield of oil to a ton of shale is 30·4 gallons.

The De Beque petroleum field in Colorado is described by G. R. De Beque.[4] The rocks are sandstone and shale of Tertiary and Cretaceous ages. Petroleum was first discovered in 1902, and much oil has been wasted in the past twelve years. The oil is golden brown, extremely viscous, and solidifies on exposure to air. It has a 32 per cent. paraffin base.

R. S. Blatchley[5] presents a review of deep drilling for oil and gas in Macoupin and Montgomery counties, Illinois, and describes structural features that appear of sufficient importance for the development of further prospecting.

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[1] *California State Mining Bureau*, *Bulletin* No. 69.

[2] *United States Bureau of Mines*, 1914, *Technical Paper* No. 70.

[3] *United States Geological Survey*, 1914, *Bulletin* No. 581*a*.

[4] *Engineering and Mining Journal*, 1914, vol. xcviii. p. 652–653.

[5] *Illinois State Geological Survey*, *Bulletin* No. 28.

J. P. Rowe[1] discusses the geological probabilities of the occurrence of petroleum and of artificial gas in Montana. The position of the State, between Alberta on the north and Wyoming on the south, leads to the supposition that the geological formations, being almost identical, the drilling operations now in progress should result in the discovery of both gas and petroleum.

V. H. Barnett[2] describes the Moorcroft oil-field, Crook County, Wyoming. Two distinct oils occur, differing widely in character. Each of these is a heavy oil, having a specific gravity above 0·9000. The higher of the two has a specific gravity of 0·9198, and is a paraffin-base oil. It contains a small amount of water, and little or no sulphur. There are only seven wells in this field that have yielded enough oil to warrant pumping, and these would probably yield about five barrels each a day.

Petroleum in the Argentine.—The occurrence of petroleum near Comodero Rivadavia, in the Chubut territory in the Argentine, is noted.[3] An area of 5000 hectares has been reserved by the Government for exploitation, and fifteen wells have been put down, nine of which are productive, and two nearly finished. Explorations are proceeding in the Neuquen territory, but up to the present the petroliferous strata, the existence of which have been determined by geological studies, have not been reached.

Petroleum in Trinidad.—J. Cadman[4] describes recent developments in petroleum mining in Trinidad. The output last year amounted to over 22½ million gallons, forty-one wells being at work. The industry is expanding, but great difficulties are encountered in boring new wells through the soft tertiary clays and sands. The quality of the oils varies widely.

Petroleum in New Guinea.—A. Wade[5] has investigated the oil-bearing deposits of Papua, and states that petroleum exists along a coastal belt from eight to twelve miles wide, extending from the delta of the Purari River almost to Yule Island. The surface indications of petroleum are said to exist over an area of 1500 square miles. The areas traversed in the course of the investigation were principally trackless jungles and sago swamps, but a study of the geology revealed the existence of valuable deposits.

Drilling for Petroleum.—The improved methods introduced in deep drilling practice in the Coalinga oil-field, California, are described by M. E. Lombardi.[1] The oil-field formation is chiefly sands and shales which will not "stand up" in an open drilling hole; the casing has to be carried close to the bit, and it is always difficult to keep it free for any considerable distance. The problem is to reach a depth of 4000 feet or more with a string pipe not less than 8¼ inch diameter for shutting off top water, and to reach this with the string free and movable and using in the upper part of the hole the minimum conductor casings. The problem has been solved by combining several methods, which are described in detail and illustrated.

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[1] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 647–649.

[2] *United States Geological Survey*, 1914, *Bulletin* No. 581*c*, pp. 83–104.

[3] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 290–291.

[4] *Journal of the Institution of Petroleum Technologists*, 1914–15, vol. i. pp. 99–126.

[5] Report to the Australian Government; *Petroleum Review*, 1915, vol. xxxii. pp. 395–396.

Properties of Liquid Fuel.—R. Schmitt[2] discusses the chemical and physical properties of liquid fuel, with special reference to the composition and qualities of mineral oils.

Refining Petroleum.—L. Edeleanu[3] gives a description of a method of refining crude petroleum by means of liquid sulphur dioxide. It is based on the treatment of the constituents of petroleum with a solvent which dissolves the hydrocarbons of the unsaturated aromatic group but leaves the saturated hydrocarbons undissolved. Such a solvent is furnished by liquefied sulphur dioxide, and as the dioxide can be recovered the operations can be performed in a cycle without appreciable loss. Tables are given showing the effect of this reagent on the chief constituents of petroleum, together with a diagram showing the various stages of refinement, and details of working results and costs. The process makes it possible to obtain illuminating oil of good quality from the greatest variety of low-grade oils; it is cheap, and the sulphur dioxide is easily obtainable even from the acid sludge available in the refining of lubricating oils.

Dehydrating Petroleum.—S. J. Hardison[4] describes the dehydrated oil plant of the Nevada Petroleum Company, California. The adoption of dehydrating methods was rendered necessary as the result of the appearance of water in the oils. The water occurs both free and as an emulsion. Free water easily settles out, but the emulsion requires treatment. Attempts were made to deal with it by means of exhaust-steam coils, but it was found that such coils cannot be successfully used for heating the oil because the temperature is not raised sufficiently high. In order that a separation of the oil and water should take place the temperature must be raised to a point that will generate steam and cause an explosion in the oil-enveloped globules of water, thereby liberating the water and permitting it to separate from the oil. After two unsuccessful experimental plants had been erected, a third was built embodying these principles and satisfactory results have since been obtained.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 209–215.
[2] *Feuerungstechnik*, 1914, vol. ii. pp. 369–375.
[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2313–2332.
[4] *Ibid.*, 1915, pp. 637–644.

Gasoline from Synthetic Crude Oil.—W. O. Snelling[1] gives the results of some experiments on the manufacture of gasoline from synthetic crude oil on a small scale. The method advocated is capable of being used on a manufacturing scale, and would form a valuable source of gasoline. A small quantity of a transparent lubricating oil was placed in a bomb-like vessel, and heated to a relatively high temperature. On removing the contents it was found that, instead of bearing any resemblance to the oil that was put in, it now had the appearance of ordinary crude oil. The material was subjected to fractional distillation, and it was found to yield 15 per cent. of gasoline and 30 per cent. of burning oil, its constitution representing crude oil quite as much as did its appearance. The gasoline and kerosene distillates were of a clear water-white colour, and were entirely free from the odour familiar in "cracked" petroleum distillates. The author repeated the experiment, and found that to obtain the result referred to above it was necessary that the vessel in which the material was heated should not be more than one-fourth full, when a very remarkable and fundamental change takes place in the hydrocarbon filling such vessel.

A new process for the separation of gasoline, benzol, and toluol from crude oil has been perfected by W. F. Rittman,[2] and is briefly described.

Petrol Substitutes.—W. Watson[3] describes tests carried out with benzol, alcohol, and various mixtures of these substances as fuel substitutes for petrol for internal combustion engines. The benzol used was a coke-oven product presented by Pease and Partners. Curves are shown comparing the mean effective pressures at 900 revolutions per minute for petrol and benzol, and the figure obtained under any condition with benzol is about the same as that obtained for petrol. The viscosity of the benzol increases with a fall of temperature much more rapidly than that of petrol. At − 4° C. benzol begins to form crystals, and it is practically solid at − 12° C., but by mixing one part by volume of petrol with three of benzol the point at which crystal formation begins is lowered to − 14° C.

Substitutes for Oil Fuel.—A. Irinyi[4] recommends the use of unrefined naphthaline as a substitute for tar-oil and petroleum, the supply of which owing to the war has been suddenly curtailed in Germany. The users of oil-fired furnaces have found themselves in a serious difficulty on this account, as it is not easy to adapt such furnaces to gas-firing. Naphthaline is a by-product of tar distillation and is plentiful enough as it is not in request as a fuel for motors.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 695-704.

[2] *Oil, Paint, and Drug Reporter; Petroleum Review*, 1915, vol. xxxii. pp. 287–288, 317.

[3] Paper read before the Institution of Automobile Engineers; *Engineering*, 1914, vol. xcviii. pp. 706–707.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1435–1436.

Economics of Petroleum Working.—C. W. Washburn[1] gives a method for the estimation of oil reserves, based on the fact that the porosity of a stratum is the measure of its maximum reservoir capacity for liquids and gases. The porosity may be determined experimentally and must be used in connection with the total volume of the sand. As, however, not all the oil can be recovered, the results should be multiplied by a fraction representing the part of the oil which can be taken out of the ground through oil wells. This fraction, which is termed the extraction factor, will vary from 60 to 80 per cent.

Production of Oil from Peat.—F. Mollwo Perkin[2] discusses the production of oils from peat and its commercial possibilities. The initial difficulty in the way of profitably extracting the oil and other by-products is to remove the large amount of water invariably held by the peat. When peat is briquetted and dried so as to contain from 18 to 20 per cent. of water, each ton on being charred produces from 5000 to 6000 cubic feet of gas, having an average calorific value of 130 British thermal units. The process once started, the gas produced by carbonisation is more than sufficient to continue the process, and there is a certain amount of residual gas which can be employed for other purposes. But when the moisture exceeds 20 per cent. the quantity of gas produced is not sufficient to carbonise completely the peat, and extra fuel has to be employed. At the plant of the Tarless Fuel Company, which is worked under a considerable vacuum, peat may be carbonised satisfactorily and the by-products collected with a lower fuel consumption than when the distillation is carried out at atmospheric pressure.

Composition of Asphalt.—C. Richardson[3] describes the composition of Trinidad asphalt.

V.—*NATURAL GAS.*

Natural Gas in the United States.—J. A. L. Henderson[4] and W. H. Henderson consider the economic value of inflammable natural gas. They show that natural petroleum gas is the only inflammable natural gas of economic value. Its occurrence is coextensive with that of petroleum, although the reverse is not always true, as is shown by the relative extension of gas and oil-fields in the United States, which in 1911 were 11,132,642 and 8,322,862 acres respectively. The most important natural gas deposits are found in the older, drier, and more consolidated, porous, sedimentary rocks, from the Cretaceous downward. In addition to the occurrences of gas in the United

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 469–471.

[2] *Journal of the Institution of Petroleum Technologists*, 1914–15, vol. i. pp. 76–90.

[3] *Journal of Physical Chemistry*, 1915, vol. xix. pp. 241–249.

[4] *Institution of Mining and Metallurgy*, 1915, *Bulletin* No. 124.

States, which easily rank first, the authors draw attention to those in Canada, Russia, Galicia, Italy, Transylvania, and England.

R. H. Johnson[1] propounds the question of what becomes of the water in oil and gas sands. As any particular sand body becomes weighted by a heavier and heavier overburden, the result of increasing deposition, a part of the very large percentage of water in the uncompacted sand and mud is forced out. The water percentage of freshly-settled mud is vastly higher than that of the resultant shales, or even of a very porous sand. If beds of less compressible material meet or underlie the shales in question there will frequently be a lateral motion along such beds to some point where the upward movement will be resumed. The practical results of the considerations set forth are that much of the world's oil is lost to recovery, and there is less hope of deep reserves than is generally believed. There are, however, enormous reserves of deep gas not only in the present producing areas but in many others, because in the absence of water many more areas will be productive of gas. As the pumps remove the dry gas in these deep pools, the oil in the shales will release some of its vapours; so that some dry gases will later on, under vacuum, become wet gases, and may be profitably compressed, the lost oil being by these means not wholly unrecoverable.

Composition of Natural Gas.—G. R. Mickle,[2] W. H. Ellis, J. W. Bain, and E. G. R. Ardagh describe the chemical composition of natural gas found in Ontario.

G. A. Burrell[3] and F. M. Siebert state that a natural gas from which gasoline is condensed on a commercial scale gave the following results upon analysis by fractional distillation *in vacuo* at low temperatures: methane, 36·8; ethane, 32·6; propane, 21·1; butanes, 5·8; pentanes and hexanes, 3·7 volumes per cent.

VI.—*ARTIFICIAL GAS.*

Gas-Producers.—V. O. Keller[4] describes the Hilger rotating grate gas-producer. The roof of the generator is provided with a hopper for admitting the charge, and a lock chamber which seals the interior of the furnace from the air during the feeding. The hearth of the furnace is in the form of an inverted bowl, and can be rotated by means of worm gear. The grate is composed of two parts, on the lower of which there is a star-shaped hood; and from this an opening of similar shape leads to the top of the grate and permits the air and steam mixture to be admitted to the furnace. By means of a simple mechanism the cogged wheel which drives the hearth can be engaged by worm wheels on either side, thus enabling the direction of rotation to be reversed and imparting a tilting motion to the ash basin. It is claimed that the consumption of fuel is more thorough with this than with other generators.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 221-226.

[2] Ontario, *Twenty-third Report of the Bureau of Mines*, 1914.

[3] *Journal of the American Chemical Society*, 1915, vol. xxxvii. pp. 392-396.

[4] *Journal für Gasbeleuchtung*, 1914, vol. lvii. pp. 80-82.

R. Klostermann[1] describes a Blezinger gas-producer, and gives particulars of a number of tests of this producer, using rough lignite as fuel.

A. H. Lymn[2] traces the development of the gas-producer with by-product recovery, and illustrates a number of types. There are about fifty by-product producer-gas plants in existence, the majority being in the United Kingdom.

H. Hermanns[3] describes the most recent practice in the construction and design of gas-producers.

Gas-Producer operated with Liquid Slag.—Many unsuccessful attempts have been made in recent years to operate gas-producers with liquid slag, but the problem has now been effectually solved by Paul Würth & Company,[4] Luxemburg. In 1912 the firm built two slagging gas-producers at a colliery of a Luxemburg ironworks company, which gave such satisfaction that two further producers on the same system have been installed. Small coke of 8 to 25 millimetres size was used, and the daily consumption of one producer is given as 60 tons. The gas is very regular in composition, containing 34 per cent. of carbon monoxide and only 1 to 2 per cent. of carbon dioxide, and the heat value varies from 1200 to 1350 calories. No pricking is necessary. A noteworthy feature is that the iron oxide in the cinder is reduced, and on tapping the slag it is recovered in the form of a high silicon sulphur-free pig iron. The gas is highly cleaned, and is used for driving large gas-engines, one large gas-producer generating 4000 horse-power. Very favourable results have also been obtained with Westphalian coal, coal-dust briquettes, and coke and briquettes. The producer will work at half capacity equally well as at full capacity, and the class of fuel can be changed without any interruption of working. No particulars are given of the method of charging and operation.

Gas-Producer Practice.—J. Gwosdz[5] reviews recent progress in the theory and practice of gas-production for industrial purposes, including the principles of modern gas-producer construction.

F. Rode[6] gives a table of the costs of operating a producer gas-power plant during each of the months in 1913. The producers were of the Smith automatic type, using hard coal in small sizes. The average coal consumption in 1913 was two pounds per kilowatt-hour. Subsequently soft coal was used, and a saving of 0·3 per cent. per kilowatt-hour was effected. The load-factor averaged 0·71 per cent. during the year.

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[1] *Giesserei Zeitung*, 1914, vol. xi. p. 633.

[2] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 253–266.

[3] *Giesserei Zeitung*, 1915, vol. xii. pp. 17–20 *et seq.*

[4] *Stahl und Eisen*, 1914, vol. xxxiv. p. 1135.

[5] *Glückauf*, 1914, vol. l. pp. 1353–1360, 1373–1380, 1400–1408, 1429–1435, 1458–1461, 1489–1494, 1514–1517.

[6] *Iron Trade Review*, 1914, vol. lv. p. 592.

Uses of Producer-Gas.—In dealing with the uses of coal-gas for industrial purposes, H. M. Thornton[1] refers to its employment in the heat-treatment of metals.

Utilisation of Blast-Furnace and Coke-Oven Gases.—K. Rummel[2] reviews the present-day applications of coke-oven and blast-furnace gases in ironworks. He points out the difficulty of pre-determining efficiency, and discusses the thermal efficiency and economic aspects of gas utilisation under various conditions. The best means of utilising available gases must be considered with reference to the special circumstances of each installation. A table is given, showing the actual "value ratio" of purified coke-oven and blast-furnace gas of the same thermal value as coal; this ratio varies from 1·0 to 1·45, and is 2·5 : 1 for coke-oven gas as compared with lighting gas. It would appear that blast-furnace gases are best suited for power applications, for the production of blast-furnace draught, for current generation, and, finally, in steelworks gas blasts. Next in order comes gas-firing in steelworks and rolling-mills. Gas should be used below steam boilers only as a last resort. On this basis, gas-engine plant is preferable to steam-turbines, whether the latter be supplied from gas or coal-fired boilers. Surplus gas supply is best used beneath boilers which are also arranged for coal-firing, and steam so produced finds advantageous application in driving rolling-mills, yielding frequently higher overall efficiency than is obtainable from any other equipment. The author has made special cost investigations, from which he concludes that steam drive is frequently preferable to electric motor drive in heavy rolling-mills.

Internal-Combustion Engines.—J. G. Walthen[3] deals with the present position of internal-combustion engines from the commercial standpoint, and points out that, in this country, the large horizontal gas-engine of more than 500 brake horse-power has not made the same progress as upon the Continent. The advantages possessed by the vertical gas-engine are now fully appreciated, and chiefly consist of their even-turning movement, which is specially suitable for electric driving. The British Westinghouse Company were the first to develop the vertical tandem-engine in large powers. The National Gas-Engine Company have within the past few years built a vertical tandem gas-engine having twelve cylinders with six cranks, and capable of developing 1500 brake horse-power. Experiments are now being carried out at the Trafford Park Works in order to obtain improved economy and higher mean-pressures, by means of which it is expected to get 150 brake horse-power per cylinder. The author gives two examples of actual power costs upon installations of vertical gas-engines. In each case bituminous coal was used, and the gas plant had a system of ammonia recovery. The figures show that the value of the by-products exceeded the cost of attendance, oil, stores, and repairs, so that the net working costs were less than the bare cost of fuel.

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[1] *Journal of the Royal Society of Arts*, 1915, vol. lxiii. pp. 401–421.

[2] *Zeitschrift des Vereines deutscher Ingenieure*, 1914, vol. lviii. pp. 1153–1160.

[3] Paper read before the Manchester Association of Engineers; *Iron and Coal Trades Review*, 1915, vol. xc. p. 403.

F. Foster[1] discusses the essential principles in engine design, and compares British and Belgian gas-engines.

R. Embleton[2] describes the construction, working, and particular advantages of the high-speed gas-engine, and defines the special fields in which its merits are peculiarly valuable.

T. R. Lonsdale[3] describes the use of gas-engines for general power purposes at the Malton Collieries.

A description is given[4] of an oil-engine for the utilisation of low-grade oil-fuel. It is valveless, and the firing is automatic. Fuel is introduced directly into the cylinder through a combination ball check-valve and nozzle, without the use of a carburettor. The cylinder is of the 2-cycle low-compression type.

H. R. Setz[5] describes at length the recent developments in the manufacture of the Diesel engine.

J. B. Merriam[6] describes a new method of recovering heat losses in internal-combustion engines.

VII.—*COAL-MINING.*

Shaft Sinking.—C. Pilkington[7] and P. L. Wood describe the sinking of the Astley Green Shaft of the Clifton and Kersley Coal Co., Ltd., at Astley, near Manchester, by the drop-shaft method and underhanging tubbing.

M. Gillieaux[8] gives a description of a new system of lining mine shafts. Its chief feature consists in the continuous fixing of the lining from the top downwards instead of building it in from the bottom upwards in sections.

C. Braunsteiner[9] describes the sinking of the Diergardt shaft No. 3

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[1] Paper read before the Manchester Association of Engineers, January 23, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 146–147, 173–175, 218–219.

[2] Paper read before the Junior Institution of Engineers, February 8, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 138–142.

[3] Paper read before the National Association of Colliery Managers; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 750–751.

[4] *Mining and Engineering World*, 1915, vol. xlii. p. 50.

[5] *Journal of the American Society of Mechanical Engineers*, 1914, vol. xxxvi. pp. 420–434.

[6] *Journal of the Cleveland Engineering Society* (U.S.A.), 1915, vol. vii. No. 4.

[7] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 303–308.

[8] *Annales des Mines de Belgique*, 1914, vol. xix. pp. 145–160.

[9] *Glückauf*, 1914, vol. l. pp. 1313–1318.

by the compressed air method. The nature of the soil through which the shaft was sunk was soft and sandy.

K. Kegel[1] discusses the modifications in the system of shaft sinking by the freezing process necessitated on reaching great depths.

Mine Timber.—The Board of Agriculture[2] has appointed a committee to inquire how far the home forestry service can be expanded, and to investigate the resources of British North America and other countries oversea. The annual consumption of mine timber in the United Kingdom is 4½ million tons, and, owing to the closing of the Baltic Sea during the war, the scarcity is likely to cause inconvenience. The leaflet issued by the Board of Agriculture describes the nature of the various timbers used and the requirements for the mines.

Thonnart[3] describes an installation for impregnating mine timber, the preservative being a liquid called "axol," a solution of oxides of copper and zinc in a mixture of ammonia and benzol. The logs are treated in a boiler filled with the liquid and subjected to a pressure of 10 atmospheres for twenty minutes. The time of the whole process is about an hour and a half.

H. A. Appel[4] deals with the preservation of mine timber and refers to the advantages of seasoning. The methods and results of applying oily preservatives by painting, spraying, and dipping are described.

J. M. Goldman[5] deals with the preservative treatment of timber, and describes the materials used and the methods of application.

Mine Supports.—The practice of using arched steel as a substitute for timber roof supports at the Pochin Colliery of the Tredegar Iron and Coal Company is described.[6]

F. N. Siddall[7] discusses the most effective means of supporting the roof in coal-mines.

W. H. Hepplewhite[8] discusses the merits of various iron, steel, and concrete pit-props as substitutes for wooden supports in longwall working.

H. Otten[9] describes a new arrangement of props and reinforced concrete headers for the support of mine workings. The novelty consists in a new method of articulation between the pillars and headers.

Subsidence.—G. Knox[10] deals with subsidence in mining, and concludes that the number of factors that may influence the results produced by the settlement of mined strata is so great that only a wide and comprehensive inquiry by geologists and mining engineers can be hoped to provide sufficient evidence to establish a definite theory to assist in overcoming some of the more common dangers due to subsidence.

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[1] *Glückauf*, 1914, vol. l. pp. 1453–1458.

[2] *Mining Magazine*, 1915, vol. xii. pp. 46–47.

[3] *Annales des Mines de Belgique*, 1914, vol. xix. pp. 132–134.

[4] Paper read before the Engineers' Society of North-eastern Pennsylvania; *Colliery Engineer*, 1914–15, vol. xxxv. pp. 481–483.

[5] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 314–317.

[6] *Iron and Coal Trades Review*, 1915, vol. xc. p. 152.

[7] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 266–283.

[8] *Ibid.*, vol. xlviii. pp. 387–399.

[9] *Glückauf*, 1914, vol. l. pp. 1360–1363.

[10] Paper read before the International Geological Congress, Canada; *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 599–600.

Equipment of Collieries.—An illustrated description is given[1] of the hydraulic decking plant at the Easington Colliery, Durham.

A. Smellie[2] describes the electrical plant at the New Cumnock Collieries, Ayrshire, which supplies power for the pumping, coal-cutting, haulage, and auxiliary ventilation below ground, and also to provide power for the driving of a washer above ground. The plant consists of two three-phase generators driven by steam-impulse turbines, each capable of developing 1000 kilowatts at 3000 revolutions per minute.

F. C. Coleman[3] describes an interesting electrification scheme which has recently been put into service at the Silkstone Colliery, near Sunderland, which utilises a large amount of available exhaust steam by means of mixed-pressure turbo-generators. Two 760-kilowatt generators of the Willans' General Electric type are installed.

Particulars are given[4] of the electric generating plant at the Manners Colliery, Ilkeston. The sets installed comprise a Belliss-and-Morcom-mixed-pressure turbine receiving high-pressure steam at 100 lbs. and exhaust steam from two pairs of winders and the fan engine at a pressure of 17 lbs. absolute. The turbine is of the slow speed type running at 1500 revolutions per minute. The set is direct-coupled to a 300-kilowatts Wilton turbo-generator, generating three-phase power at 440 volts, 25 cycles.

A description is given[5] of the electrical equipment of Sneyd Colliery, Burslem, which has developed from a small lighting plant to complete electrical operation.

C. P. Sparks[6] deals with the application of electricity to mining, and describes recent additions to the power plant of the Powell Duffryn undertaking. The plant now in use by the Company in the Aberdare and Rhymney Valleys is rated at 24,000 kilowatts, the motors being of 44,800 brake horse-power, which represents about 60 per cent. of the total power requirements.

A description is given[7] of the new power station at the Deep Duffryn Colliery. The units at present installed consist of two turbines of the mixed-pressure type, each of 1000 kilowatts normal capacity, running at 1500 revolutions per minute. High-pressure steam is supplied at 120 lbs. and exhaust at 17 lbs. absolute.

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[1] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 798.

[2] Paper read before the Association of Mining Electrical Engineers, Feb. 20, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 368–369.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 111–112.

[4] *Ibid.*, p. 182.

[5] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 137–139.

[6] *Journal of the Institution of Electrical Engineers*, 1915, vol. liii. pp. 389–438.

[7] *Iron and Coal Trades Review*, 1915, vol. xc. p. 402.

R. Nelson[1] shows the growth of the use of electricity in the mines of the United Kingdom. The number of electrically-driven coal-cutting machines in use at the end of 1913 was 1307. During that year there were in all fifteen fatal accidents definitely due to the use of electricity. The number of non-fatal accidents amounted to fifty-three.

H. Leyval[2] gives data resulting from a number of running tests on the new electric winding-engine of the Anderny-Chevillon Collieries, France. The depth of winding is 224 metres, and the daily coal output 5000 tons, 5 tons being raised per wind. The period of winding the loads, including stoppages, is on an average 46 seconds. Two Lentz cross-compound engines of 1200 horse-power, capable of generating 1600 horse-power at a maximum load, are coupled up to dynamo of 685 kilowatts, and an alternator of 3000 volt 50-cycles.

Modern progress in the application of electricity to coal-mining and the present state of the industry, together with a forecast of the further applications possible, are dealt with by J. Libert[3] in his inaugural address to the Engineers of the Montefiore Electrotechnical Institute.

L. Foster[4] describes the progress of electricity in its application to the coal-mining industry.

L. Foster[5] discusses some typical breakdowns in colliery electrical installations, and means for their prevention.

Compressed Air in Collieries.—The air compressor installation at the Glass Houghton Colliery is described.[6] The compressor is of the standard vertical two-crank double-acting type, and is driven by a mixed-pressure turbine.

Coal-Cutting Machines.—According to E. W. Parker,[7] the substitution of mechanical methods for hand labour in the bituminous coal mines of the United States during the last quarter of a century has been one of the most interesting features connected with that branch of the industry. In 1891 there were 545 machines in use, while in 1913 there were 16,381 machines. The most popular types of machines now in use are the pick or puncher and the chain-breast. Out of the total of 16,381 machines in use in 1913, 6936 were of the chain-breast type, 6327 were punchers, 2210 were shortwall, 791 were longwall, and 117 were of the radial axe or post-puncher type. One of the determining factors in the choice of machines for undercutting the coal is the character of the roof, it being impracticable to operate chain-breast machines when the roof is tender and the timbering has be kept up close to the face. This limitation does not apply to the shortwall or continuous-cutter machines, which can be operated where the timbering is within 3 feet of the face.

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[1] Home Office, *Mines and Quarries; General Report with Statistics for* 1913, Part II. pp. 97–103.

[2] *Bulletin de la Société de l'Industrie Minérale*, 1914, Series V., vol. vi. pp. 63–109.

[3] *Bulletin de l'Association des Ingénieurs électriciens Sortis de l'Institut électrotechnique Montefiore*, 1914, Series III., vol. xiv. No. 1; *Revue Universelle des Mines*, 1914, Series V., vol. vi. pp. 318–322.

[4] Paper read before the Association of Mining Electrical Engineers; *Iron and Coal Trades Review*, 1915, vol. xc. p. 717.

[5] Paper read before the National Association of Colliery Managers; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 21–22.

[6] *Iron and Coal Trades Review*, 1915, vol. xc. p. 570.

[7] *United States Geological Survey, Mineral Resources for* 1913, Part II., pp. 759–765.

Methods of Working Coal.—J. D. Paton[1] describes modern developments in hydraulic stowing, and suggests the application of this system to the recovery of abandoned coal in the Staffordshire coal-field.

S. O. Andros[2] describes coal-mining practice in Illinois. The average room-and-pillar mine in this State extracts only about 50 per cent. of the coal in the bed. Fear of surface subsidence has prevented the drawing of pillars in many of the mines, but two mines, however, obtain an extraction of coal almost equal to that obtained by longwall working.

S. Dean[3] describes the methods of mining coal in the State of Pennsylvania.

The methods of mining thick coal-seams of steep pitch, such as occur in the Lehigh Valley coal-field, are described and illustrated by diagrams by W. G. Whildin.[4]

J. S. Quigley[5] describes the two principal methods in vogue in Canadian mines of drawing pillars in pitching seams.

The present position of hydraulic packing in the chief coal-mines in France, Belgium, Germany and Russian Poland is discussed exhaustively and illustrated by diagrams by Frantzen.[6]

A. W. Hesse[7] discusses what should be considered the maximum recovery in mining bituminous coal by modern methods.

P. Meuss[8] discusses the economical and technical considerations involved in removing safety pillars in coal-mines. The operation of winning the pillars in a Westphalian colliery and replacing them by packing was successfully and profitably carried out, the method being fully described.

W. Z. Price[9] describes and illustrates the method of coal stripping in open cuts in Kansas, and the different methods of raising the coal from the excavations.

An illustrated description is given[10] of the Myers-Whaley shovelling machine for loading coal at the face. The machine is operated by one man, and either electricity, petrol, compressed air or steam may be employed for power. It is self-propelling, and either runs on a track or may be equipped with traction wheels. The machine is designed to work in a space as low as 47 inches from the top of the rail to the roof. The machine will load at an average rate of 10 to 20 tons per hour.

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[1] Paper read before the South Staffordshire and Warwickshire Institute of Mining Engineers, April 19, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 572–573.

[2] Illinois University: *Bulletin* No. 9.

[3] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlviii. pp. 367–386.

[4] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2795–2819.

[5] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 406–414.

[6] *Bulletin de la Société de l'Industrie Minérale*, 1914, Series V., vol. vi. pp. 5–61.

[7] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 13–16.

[8] *Glückauf*, 1915, vol. li. pp. 262–267.

[9] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 285–288.

[10] *Iron and Coal Trades Review*, 1915, vol. xc. p. 333.

Uses of the Hydraulic Mining Cartridge.—J. Tonge[1] refers to the disadvantage and danger of employing explosives to excavate rock in confined places. As a substitute for blasting the hydraulic mining cartridge has considerable advantages. It consists of a steel cylinder containing a number of telescopic pistons operating at right angles, which expand on the application of water from a hand hydraulic pump attached to the cylinder. The cylinder is placed in a suitably drilled hole, and as the operation proceeds the rock slowly fractures, being left in a condition suitable for speedy removal. It is possible to excavate greater areas at one operation than with explosives, and there is only slight crushing of the rock before the pressure causes the mass to bend and crack.

Mine Drainage.—M. Vahle[2] discusses the difficulties of unwatering very deep mines. At a certain colliery in the Ruhr district, with a depth of 850 metres, centrifugal pumps alone have proved satisfactory, and they would without doubt prove equally efficient at depths of over 1000 metres. An installation is described which has been in continuous operation for three years.

R. H. Willis[3] discusses the advantages of the turbine pump for use in collieries.

C. Dickinson[4] describes the use of dams for stopping an inburst of water at the Netherseal Colliery. Five dams were put in, in the coal headings near the point of the outburst. The site of the dams was 1½ miles from the shafts, and the material had to be handled by five different haulages.

Haulage in Mines.—G. M. Eaton[5] discusses the development of the electric locomotive for mine haulage from 1896 until the present time. The design of electric locomotives for such purposes is fully dealt with.

A new type of aerial tramway for mining cliff coal in the Book Cliff range, Utah, where the coal is exposed for the most part in flat escarpments, is described and illustrated by A. E. Gibson.[6] The tramway is electrically driven, and has been designed for an hourly capacity of 60 tons, provision for doubling being provided for.

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[1] *Transactions of the Society of Engineers*, 1914, pp. 285–307.

[2] *Glückauf*, 1915, vol. li. pp. 81–84.

[3] Paper read before the National Association of Colliery Managers; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 23–24.

[4] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlviii. pp. 400–408.

[5] *Proceedings of the American Institute of Electrical Engineers*, 1914, vol. xxxiii. pp. 517–528.

[6] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2537–2546.

J. Shanks[1] describes various methods of haulage in coal-mines.

A. Kiesel[2] gives an account, accompanied with diagrams, of an underground haulage installation with endless ropes, in operation in a colliery at Beuthen, Upper Silesia.

Winding-Engines.—A description is given[3] of the new electric winding-engines at the Lumley Sixth Colliery, near Durham. They are operated on the Ward-Leonard system, with continuous-current winding motor and variable-voltage control. The engines are designed to raise a net load of 34 cwts. a distance of 160 yards in 30 seconds and to give 60 complete winds per hour.

F. Wintermeyer[4] considers the practicability of raising coal by means of continuously running conveyers. Some installations are described involving the use of conveyers, consisting of buckets carried on endless chains, but these can only be used where the workings are of no great depth, as in most of the German brown-coal mines.

G. G. T. Poole[5] deals with the prevention of overwinding and overspeeding in shafts.

Winding-Ropes.—H. W. G. Halbaum[6] submits a formula connecting the various factors which determine the amount of lateral friction encountered by a winding-rope as it travels from one side of the drum to the other.

F. Baumann[7] discusses the factor of safety in winding-ropes, and gives tables of safe loads for ropes of various lengths and diameters.

F. Herbst[8] makes various recommendations as to the calculation of the factor of safety of winding-ropes, and in particular for ropes for winding from great depths. The adoption of Körfer's proposal to take separate account of the weight of the cage and of the weight of the rope is strongly advocated. For lowering or bringing up the shifts the load on the rope should never exceed 90 per cent. of the winding load, and when the rope at its weakest part has lost 20 per cent. of its original strength it should be discarded.

Ventilation of Collieries.—An illustrated description is given[9] of a large fan recently constructed by the James Keith and Blackman Company, Ltd., for a colliery in South Wales. It is capable of exhausting 400 thousand cubic feet of air per minute from the pit, against a static resistance of six inch water gauge in the inlet drifts, and requires about 500 horse-power for driving.

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[1] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 415–428.

[2] *Glückauf*, 1914, vol. l. pp. 1269–1276.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 183.

[4] *Glückauf*, 1915, vol. li. pp. 209–214.

[5] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 355–380.

[6] *Ibid.*, pp. 125–158.

[7] *Glückauf*, 1914, vol. l. pp. 1293–1298.

[8] *Ibid.*, 1915, vol. li. pp. 1–6, 29–37.

[9] *Engineering*, 1915, vol. xcix. p. 270.

Lighting of Collieries.—An account is given[1] of a general discussion which took place at a meeting of the Manchester Geological and Mining Society on the use of electric lamps in coal-mines.

F. Whittaker[2] describes the use of intensified gas for lighting colliery premises.

C. Johnson[3] relates his experience of working for twelve months with the Ceag electric safety-lamp.

C. Beyling[4] reports on the illuminating power of various kinds of safety-lamps, using oil, benzine, acetylene and electricity. Benzine lamps vary from 0·7 to 1·3 hefner candle, electric lamps from 1 to 1·5, and acetylene lamps are capable of giving 3 to 4 hefner units.

C. Beyling[5] has made experiments with the object of finding suitable substitutes for benzine for use in mine safety-lamps. Since the scarcity of benzine has become acute, it is necessary to search for means of economising the supply. Benzol has been tried, but is too smoky, and the only way of meeting the difficulty at present is to use a mixture of benzine and benzol, in which the proportion of benzol cannot conveniently exceed 10 per cent.

G. A. Meyer[6] has made practical tests with mine-lamps using mixtures of benzol as a substitute for benzine. Two mixtures gave quite satisfactory results: (1) a mixture of 75 per cent. spirit with 25 per cent. benzol; (2) 50 per cent. spirit, 20 per cent. benzol, and 30 per cent. benzine. These showed no tendency to separate, and the consumption per shift with round wick lamps was 60 to 70 grammes of No. 1 mixture and 50 to 60 grammes of No. 2 mixture. Flat wicks consumed about 5 to 10 grammes more per shift.

W. Maurice[7] discusses the design and equipment of colliery lamp-rooms.

Underground Fires.—The method of fighting a fire, which occurred at the Albion mines of the Acadia Coal Company, Nova Scotia, is described.[8] In this work oxygen helmets proved indispensable.

Gases in Mines.—G. A. Lavoie[9] deals with the occurrence of gas in coal-beds.

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[1] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 730.

[2] Paper read before the National Association of Colliery Managers; *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 641.

[3] Paper read before the National Association of Colliery Managers, February 15, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 339–340.

[4] *Glückauf*, 1914, vol. l. pp. 1425–1428.

[5] *Ibid.*, 1915, vol. li. pp. 157-164.

[6] *Ibid.*, pp. 233–235.

[7] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlviii. pp. 619–662.

[8] *Canadian Mining Journal*, 1914, vol. xxxv. pp. 761–762.

[9] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 487–492.

Gases in Mines.—W. H. McMillan[1] deals with the detection and estimation of fire-damp.

Coal-Dust Experiments.—R. Cremer[2] reviews the results of recent experiments in the use of incombustible dust as a means for the prevention of explosions in collieries and of underground fires.

F. Haas[3] discusses the origin, occurrence, and behaviour of the gases usually found in mines.

Coal-Dust Explosions.—H. N. Eavenson[4] discusses the coal-mine explosions caused by gas or dust in the United States, Canada, and Mexico during the past forty years, and gives tables showing the fatalities that have occurred owing to such explosions in the United States, Great Britain, France, and Belgium, the tables in each case extending over a lengthy period and commencing, in the case of Great Britain, as far back as the year 1803.

J. D. Morgan[5] deals with coal-dust explosions, and discusses the inflammability of coal-dust clouds, and the effect of the surface of mine workings on coal-dust explosions.

G. S. Rice[6] has carried out some investigations on coal-dust explosions with special reference to the conditions existing in collieries in the United States. The method of conducting tests is described, and various means of obviating coal-dust explosions are discussed, and illustrated by diagrams and photographs.

G. S. Rice[7] describes the use of rock-dust barriers in order to confine coal-dust explosions to their originating area. Taffanel was one of the first investigators to observe the important effect these barriers had in checking explosions. The author describes some special forms of enclosed barriers designed by himself.

Explosions in Collieries.—The report on the inquiry conducted into the explosion that occurred on May 30, 1914, at the Wharncliffe Silkstone Colliery, near Barnsley, has been issued by the Home Office, and an abstract of the report has appeared elsewhere.[8]

L. T. O'Shea[9] gives some notes on the explosion which took place at the Wharncliffe Silkstone Colliery. The two points in connection with this explosion to which the author gives special attention are (1) the rapid accumulation of gas in a small area during the stoppage of the fan, and (2) the development of the explosion.

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[1] Lecture before the National Association of Colliery Managers, February 20, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. p. 329.

[2] *Glückauf*, 1915, vol. li. pp. 105–115, 133–138, 185–190.

[3] Paper read before the West Virginia Mining Institute; *Colliery Engineer*, 1914–15, vol. xxxv. pp. 375–379.

[4] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2637–2660.

[5] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 220–235.

[6] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2459–2492.

[7] *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 667–668.

[8] *Ibid.*, pp. 725–727.

[9] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 289–320.

Accidents in Collieries.—T. J. Nelson[1] discusses the precautions necessary for the prevention of electrical accidents in mines.

Rescue Appliances.—C. Hanmer[2] traces in detail the evolution of the modern oxygen regenerative breathing apparatus from the first of its kind, which was invented by Schwann in 1853.

Particulars are given[3] of a scheme to establish mine rescue stations in various parts of the United States, and to place in each mining centre a thoroughly trained and competent team of rescue and first-aid men.

A memorandum has recently been issued by the Home Office on schemes of training and practice in connection with rescue work in mines. An abstract of this appears elsewhere.[4]

A report of the committee appointed by the United States Bureau of Mines to develop an efficient method of resuscitation from mine gases has appeared.[5]

C. Graham[6] describes the Draeger and Fleuss types of mine rescue apparatus.

Safety in Mines.—The safety methods and organisation of the United States Coal and Coke Company, Pocahontas coal-field, McDowell county, West Virginia, are described by H. N. Eavenson.[7] He reproduces synopses of the instructions used as regards ventilation and inspection, explosives and shooting, trackwork, line sights, timbering, slate work, and electric work generally.

Storage of Coal.—A detailed description is given[8] of tests made with various coals to show the tendency to deteriorate in storage or to develop heat spontaneously.

The storage of bituminous coal with reference to the loss of heat units, prevention of spontaneous combustion, and the methods of handling, is dealt with.[9]

Methods of storing coal under water are described,[10] together with the construction of the storage pits and the methods of loading and unloading the coal.

J. B. C. Kershaw[11] describes modern systems of coal storage and types of storage bins.

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[1] Paper read before the Association of Mining Electrical Engineers; *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 701–704.

[2] Paper read before the National Association of Colliery Managers, January 16, 1915.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 397.

[4] *Ibid.*, p. 325.

[5] *United States Bureau of Mines*, 1914, *Technical Paper* No. 77.

[6] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 364–373.

[7] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 413–430.

[8] *Gas Engine*, 1915, vol. xvi. pp. 742–749.

[9] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 231–235.

[10] *Ibid.*, pp. 298–302.

[11] *Gas World*, 1915, vol. lxi. pp. 601–603.

Economics of Coal-Mining.—H. M. Chance[1] deals with the valuation of coal lands for the purposes of taxation, and gives a long list of suggestions which have been made from time to time with a view to the equitable solution of the problems involved.

The nature of the title that should be granted by governments for the working of mineral lands is discussed by G. W. Riter,[2] who points out the confusion which so often exists as to the nature of mining rights in concessions the nature of which is insufficiently defined.

W. H. Grady[3] deals with a number of cost factors in coal production. These involve a method of working and the daily output per panel, together with such considerations as those of loading, haulage, and winding. When changes in the method of procedure and plan of mining can be made without involving capital expenditure much greater concentration can be effected, resulting in decreased cost of production, increased percentage of recovery, and higher daily earnings to miners; while at the same time reducing the amount of labour, material, and equipment in use.

W. B. Woodhouse[4] discusses the principal working conditions affecting the cost of power in collieries.

VIII.—*COAL WASHING AND SCREENING.*

Coal Handling.—L. Llewellyn[5] describes the plant of the Lilley Coal and Coke Co. This plant is arranged to load coal upon either railroad cars or river barges. No hand trimming is necessary in the operations.

C. O. Bartlett[6] describes the Cobasco system for handling materials, such as coal and coke.

J. F. Springer[7] deals with methods of handling coal, and describes several large installations in America.

J. F. Springer[8] describes and illustrates the appliances at the Panama Canal for the loading, unloading, and storing of coal.

The coal storage and handling plant at the Brier Hill Steel Company, Youngstown, Ohio, is described and illustrated.[9]

Coal Briquetting.—The manufacture of coal briquettes in France is described by C. Lambotte.[10] The importance of the briquetting industry is shown by the fact that, in 1911, over 13¾ million tons were produced, of which Germany produced nearly 5 million tons, Belgium 2¾ million, France 1½ million, and Great Britain over ¾ million tons. The dust-coal used in France is of a lean bituminous variety, containing 8 to 15 per cent. of volatile matter. Pitch is chiefly used as a binder. The principal considerations to be taken into account, such as size of grain, porosity, nature of binder, and temperature and degree of pressure, are discussed in detail.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 1461–1466.
[2] *Ibid.*, pp. 1667–1670.
[3] *Ibid.*, 1915, pp. 1035–1072.
[4] *Transactions of the Institution of Mining Engineers*, 1915, vol. xlix. pp. 2–34.
[5] *Coal Age*, 1914, vol. vi. pp. 591–596.
[6] *Mining and Engineering World*, 1915, vol. xlii. pp. 369–370.
[7] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 131–141.
[8] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 86–87.
[9] *Steel and Iron*, 1915, vol. xlix. pp. 425–427.
[10] *Revue Universelle des Mines*, 1914, Series V., vol. vi. pp. 286–310.

Recent developments in coal briquetting are dealt with by C. T. Malcolmson[1] with special reference to American practice. In this connection, he describes the Rutledge briquetting press and fluxer, which is employed for briquetting purposes with a liquid binder. A thorough blending of the coal and binder is of prime importance, and the fluxer is designed to effect this mixture, asphalt obtained from the distillation of petroleum being used as the binder. The press itself is of the continuous-mould type, and the briquettes are cylindrical in shape, with spherical ends. The capacity of the press is 32 to 33 tons of briquettes per hour.

T. Dach[2] describes the process of Fohr-Kleinschmidt for briquetting coal, using pitch and tar as the binder. The chief advantage is a saving of 1 per cent. of pitch in comparison with the older methods of briquetting.

W. L. Kidston[3] describes a new plant for briquetting coal where asphalt is used as a binder. The plant has a capacity of about 1,000,000 briquettes for a 10-hour shift.

C. M. Lewis[4] describes the coal-briquetting plant of the Pacific Coal Company, at Briquetville, near Renton, Washington, U.S.A. Asphalt is used as a binding material, this being the first plant to use it on a large scale.

Coal Washing.—The coal-washing plant at the Coedely Colliery is described[5] and illustrated. The plant has a capacity of 80 tons per hour. The screens are of the four-tray double-balance types, driven by a centre crank. The washing units consist of five nut-washers and six feldspar washers, these last being of the double-box type. The washed coal is delivered by means of troughs and water into a series of seven draining bunkers having a total capacity of about 700 tons.

The Wendell continuous automatic machine for drying washed coal is described.[6] At the coal washery of the Woodward Iron Company, Alabama, three of these machines are in operation, taking coal from elevators with a content of 30 or 40 per cent. of moisture. They deliver the coal for use in by-product ovens with 8 per cent. of moisture.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 271–289.

[2] *Glückauf*, 1915, vol. li. pp. 281–284.

[3] *Coal Age*, 1914, vol. vi. pp. 869–870.

[4] *Colliery Engineer*, 1914–15, vol. xxxv. pp. 227–231.

[5] *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 693–695.

[6] *Ibid.*, 1915, vol. xc. p. 686.

The coal-washing plant at the Manners Colliery, Ilkeston, is described and illustrated.[1]

Coal Screening.—The new Turnbull screening-conveyer plant at the Landsale Pit, Gateshead, is described.[2] The plant has a capacity of 30 tons per hour, and is driven by a 20 horse-power motor. The coal is divided, as it progresses along the screen, into three classes. Perforated sheets are employed for the separation of the smallest size, but for the other sizes a novel arrangement of tapered slots is used.

An illustrated description is given[3] of the new coal-screening plant at the Choppington Colliery.

[1] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 597–598.

[2] *Ibid.*, p. 54.

[3] *Ibid.*, pp. 470–471.

PRODUCTION OF IRON.

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I.—*BLAST-FURNACE PRACTICE.*

Blast-Furnace Construction.—J. E. Johnson, Jun.,[1] deals in detail with the construction of the blast-furnace stack itself, and specially discusses the chemical and mechanical action of the materials of the burden on the lining. Methods of minimising the injurious effects of the action, which differs in different zones of the stack, are discussed.

J. E. Johnson, Jun.,[2] continues his description of the design and construction of the blast-furnace, with special reference to the practice of introducing cooling plates above the mantle to minimise the corrosive action of the burden on the lining at this place. The principles underlying the design of the furnace top are also discussed and various forms of construction illustrated. A comparison of the advantages of thin-lined furnaces over the older form is also instituted, and the various innovations necessitated in the mode of carrying the shell exemplified by an illustrated description of the "Ashland" form of construction.

A. E. Maccoun[3] discusses the trend of modern blast-furnace construction in America. The construction of the bosh has been greatly strengthened. The bosh usually preferred is protected by bronze cooling plates and heavily banded to give the necessary strength. Different styles of construction are also used in placing the cooling plates in the bosh, such as brick arches, cast-iron boxes, and others bricking in the plates solidly, without arches or boxes. The steep bosh angle, approximately 79°, is preferred. Furnace shells of heavy steel plate construction are now being used, the thin-lined shell not having been so successful as was hoped for. In the author's opinion a modern 500-ton furnace should have an equipment of four stoves of approximately 22 feet diameter and 100 feet in height, each containing 60,000 square feet of heating surface. There should then be no difficulty in carrying a straight line heat of 1200° F., and still have plenty of reserve in case of need. In addition the average stack temperature for such stoves should be comparatively low, not exceeding 400° F. Experiments carried out on firebrick as used in hot-blast stoves to ascertain the temperature at certain distances back from the face of the brick, tend to prove that, except for the need for structural strength, it would be more economical to make the checker walls as thin as possible, and the checker openings small so as to obtain the greatest heating surface on account of the greater heating effect of the surface of the brick compared with the interior. The maximum possible heating surface of a stove containing square checkers might be determined by dividing the product of the total checker area and its height by the thickness of the checker brick used.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 451–460.

[2] *Ibid.*, pp. 497–506.

[3] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1915, vol. xxx. pp. 935–972.

Blast-Furnace Operations.—The adoption of high-blast heats in Mesaba practice is considered by W. Mathesius.[1] High-blast heats on furnaces melting Mesaba ores are still the exception, the average blast temperatures seldom reaching 1100° F., and when, some fifteen years ago, the use of fine Mesaba ores in larger proportion to the total burden first came into practice, it was difficult to employ even those heats which had been possible with the old range ores. The furnaces suffered from irregular stock movement, which impaired the practice and increased the coke consumption, but by lowering the blast temperature the working became smoother and the bulk of Mesaba furnaces have ever since operated on very low blast temperatures, ranging between 800° and 1000° F. This has, however, served to hamper present-day practice, as there is a disadvantage in hot blast stove equipment, so that where proper furnace lines have been adopted and conditions are now favourable to the successful employment of higher blast temperatures, the heats required for the greatest fuel economy are not available. With proper furnace conditions it is not only possible, but profitable, in coke economy to carry high heats on Mesaba furnaces. Data for the necessary heat calculations are given.

A. J. Boynton[2] deals with a few points of interest to blast-furnace managers, the neglect of which may lead to trouble being experienced in regard to sulphur. The necessity of regular composition, and in particular of uniform distribution and movement of the burden is emphasized.

A. Morette[3] deals with some of the more obscure problems encountered in blast-furnace practice. Broadly speaking, the satisfactory working of a furnace depends upon three factors: the temperature, the composition of the gaseous "phase," and the influence of the physical conditions of the ores on the speed of reactions. Of these the latter seem to play a very important part. By-product economies are valuable, but not so much on their own account as for their general effect in cheapening the principal product, pig iron.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 539–555.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 433–434 and 454*c*.

[3] *Bulletin de la Société de l'Industrie Minérale*, 1914, Series V., vol. v. pp. 217–293, 454–542.

C. C. Lynde[1] describes the method of operating the blast-furnace of the Stewart Iron Company at Sharon, Pa.

Blast-Furnace Calculations.—R. Chauvenet[2] gives a number of rules and formulæ for working out mixed charges of ores. The problems dealt with are: (1) the mixing of ores to suit a required percentage of any constituent; (2) the mixing of ores for a definite slag; and (3) the consideration of the amount of lime to be added. Calculations based on the assumption of a unit amount of the principal ore in the mixture are also given, with the resulting slag calculations.

The heat balance of the blast-furnace is calculated by S. Cornell,[3] who gives tables and data derived from six 600-ton blast-furnaces, and takes into consideration all the available factors relating to hot blast, heat generation and absorption, the hot-blast stoves, and the duty and behaviour of the blowing engines.

G. Geijer[4] takes up again the subject of his former investigations[5] on the economy of the blast-furnace. In this instance he apportions the whole of the amount of heat supplied among the pig, slag, and gases. The following are among his conclusions: (*a*) if the temperature of the waste gases can be lowered by 50 per cent. it results in a saving of 1·5 per cent. of fuel (charcoal); (*b*) if the degree of oxidation of the ore can be raised 1 per cent., this will reduce the fuel by 2·7 per cent.; (*c*) a rise of 5 per cent. in the amount of pure iron in the ore will represent a saving of 6·5 per cent. of fuel.

B. Osann[6] discusses the development of the methods of calculating blast-furnaces charges. All methods give only approximately correct values and must be modified to suit local conditions. Examples illustrated by means of tables are given of a simple method of calculation. By regarding slags as solutions and not as chemical compounds it will be better understood why small additions and slight variations in the composition of the charge often produce an extraordinary and quite unlooked-for effect.

Blast-Furnace Reactions.—V. Falcke[7] gives the result of his investigation of the reactions between ferrous oxide and carbon, and between carbon monoxide and iron at temperatures from 600° upwards. He has also examined the gaseous products obtained when the reaction mixtures were dissolved in hydrochloric acid.

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[1] *Steel and Iron*, 1915, vol. xlix. pp. 416–419.
[2] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 626–630.
[3] *Ibid.*, pp. 747–750.
[4] *Bihang till Jernkontorets Annaler*, 1914, pp. 135–184.
[5] *Ibid.*, 1911, p. 727.
[6] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1450–1456.
[7] *Zeitschrift für Elektrochemie*, 1915, vol. xxi. pp. 37–50.

Use of Raw Coal Dust as Blast-Furnace Fuel.—F. Lange[1] publishes some notes on the use of raw coal as fuel in blast-furnaces. He proposes to use fine coal dust, which is admitted by blowing streams of such dust through the tuyeres conveying the blast.

Smelting Foundry Iron.—R. Sharp[2] describes modern blast-furnace practice in the manufacture of foundry pig iron in the Cleveland district, and compares it with the principles laid down by Sir Lowthian Bell over thirty years ago. The following table shows the consumption of materials per ton of pig :—

	1884.	1914.
	Cwts.	Cwts.
Raw ironstone . . .	63	70
Limestone	11	14
Coke (average practice) .	21	24

The coke used at the present time is nearly all produced in by-product ovens. The sulphur in the ironstone has increased, and sometimes is as high as 1 per cent., necessitating a more calcareous slag now than was formerly necessary. The amount of slag now is about 34 cwts. per ton of pig, as against 27·9 cwts. in 1884. In present-day practice, in spite of the saving of 4,142 calories by the use of calcined limestone, there is still a total heat requirement of 6209 calories greater than was required in 1884.

Smelting Minette Ores.—M. Zillgen[3] illustrates and describes the blast-furnace plant of the Gelsenkirchener Company at Esch and Audun-le-Tiche, in the minette districts of Luxemburg and Lorraine. The company owns three important ironworks, the most modern of which is the Adolf-Emil Hütte at Esch, consisting of six blast-furnaces, with a total daily capacity of 1500 tons. In discussing the practice in smelting dusty minette ores, it is said that some furnace managers prefer to work at a low pressure in order to prevent the loss of dust as far as possible. Others drive the furnace at high pressure in order that the dust may be carried off by the gases. The author holds that the latter system is undoubtedly the right one. The quantity of dust carried over depends not so much on the blast pressure as on the velocity of the waste gases. In ordinary working the dust amounts to about 7 to 8 per cent. of the ore charged. At the ironworks in question the dust is briquetted by the magnesium chloride process, the briquettes containing 36 per cent. of iron, 1 per cent. of manganese, and 7 per cent. of coke.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 265–268.
[2] *Proceedings of the Cleveland Institution of Engineers*, 1914–15, pp. 128–174.
[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1325–1330, 1374–1379.

Manufacture of Charcoal Pig Iron.—E. C. Kreutzberg[1] points out that the manufacture of charcoal pig iron is now confined in the older States to five blast-furnaces in Western Massachusetts and Connecticut, there being two in the former State and three in the latter. The ore used is the brown hæmatite from the Berkshire hill deposits. The industry still flourishes and shows no signs of decreasing. The iron made is of close-grained texture, possessing great tensile and transverse strength, and is much used as a strengthener in foundry mixtures. An illustrated description of the Richmond Ironworks, where charcoal pig has been continuously made since 1827, is given. In 1893 the state of trade was such that stocks accumulated greatly, but, with this exception, the running of the furnaces and of the works has been even and uneventful. The furnace originally had a stone hearth and stack and an open top, blast being supplied by means of a water-wheel. It is thirty years ago that the first warm blast stove was supplied. The plant is now quite up-to-date for the special practice undertaken, and the production, which is between 10,000 and 12,000 tons annually, could be considerably increased if necessary. There are seven charcoal kilns and storage accommodation for 200,000 bushels of charcoal.

Smelting of Manganiferous Ore.—H. Thaler[2] has investigated the thermal conditions of the reduction of manganese in the blast-furnace, and has calculated the heat balance and balance of input and yield of materials for spiegeleisen containing 6·02, 10·83, 12·90, and 20·32 per cent. of manganese. The main results show that the reduction of manganese can take place indirectly as well as directly; the fuel consumption rises with increasing reduction of manganese; hot-working and high waste-gas temperature favour the reduction; the losses of manganese in the slag are lower, the higher the percentage of manganese in the ore; the basicity of the slag must approach that of a 0·8 to 1·0 silicate; the manganese in the slag amounts to 8 to 10 per cent.; the proportion of manganese to silicon in the charge must neither exceed nor fall below a definite limit; the losses by volatilisation are small with low-grade spiegel, but rise rapidly with an increased reduction of manganese, and amount to 7 to 8 per cent. with 20 per cent. spiegel. The losses in the form of dust do not exceed 1 per cent.

Manufacture of Ferro-Manganese.—The history and manufacture of ferro-manganese is dealt with by R. M. Keeney.[3] The industrial importance of ferro-manganese began in 1856 with the introduction of the Bessemer process, which required a strong deoxidising agent.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 65–67.
[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1481–1484.
[3] *United States Bureau of Mines, Bulletin* No. 77, pp. 141–145.

In 1866 Prieger made in the crucible some ferro containing 70 to 80 per cent. of manganese. At Terre-Noire, a little later, it was made in the open-hearth furnace and crucible in a combination process. The first ferro-manganese to be made in the blast-furnace was produced in Sweden in 1873, and contained 33 per cent. of manganese. In 1875 at Terre-Noire, Pourcel made in the blast-furnace some ferro that contained 75 to 80 per cent. of manganese. The results of a modern typical blast-furnace run, including figures as to the ore used and the slag and the alloy produced, are given in the following table. In this run the average amount of coke consumed was 2·37 tons per ton of ferro produced. Of the total manganese charged 76·9 per cent. was recovered, and 23·1 per cent. lost.

Ore.

	Per Cent.
Mn	51·6
Fe	1·45
P	0·173
SiO_2	7·80
Al_2O_3	1·12
CaO	1·80
MgO	2·18
BaO	2·20

Slag.

SiO_2	30·32
FeO	1·41
MnO	8·52
Al_2O_3	10·88
CaO	41·34
MgO	2·96
P_2O_3	0·01
CaS	3·94
BaO	0·48

Ferro-Manganese.

Mn	80·20
Fe	11·80
Si	1·16
P	0·38
C	6·46

The loss of manganese by volatilisation, or as dust, varies between 15 and 20 per cent. of the total quantity of manganese charged. The average total loss is about 30 per cent., of which 10 per cent. goes to the slag, and 20 per cent. is volatilised or lost as dust. Any phosphorus in the ore goes to the metal, but there is no difficulty in slagging the sulphur. No more than 0·02 per cent. of phosphorus should be present for each 10 per cent. of manganese in the ore. When ferro-manganese is being made in the electric furnace, the electrodes and voltage are regulated so as to prevent arcing. With a mixture of 813 parts of ore containing 30 per cent. manganese, 178 parts of anthracite coal (4 to 5 per cent. ash), and 90 parts of fluorspar, about 450 pounds of product were obtained per ton of mixture treated. The products contained 85 per cent. of manganese. Of the total manganese charged 26·8 per cent. was lost by volatilisation, as dust, and in the slag. Ferro-manganese made in the electric furnace has considerably lower carbon content than blast-furnace ferro, and is used in the molten state for the manufacture of silico-manganese.

Smelting of Titaniferous Ores.—C. T. Starke[1] gives details of experiments made at the Cedar Point furnace, Port Henry, New York, in using magnetic ores containing titanium, of which vast reserves exist in the United States, in the Lake Sanford district and elsewhere. The experimental runs extended for two months, about 8000 tons of titaniferous crude ore being put through the furnace in concentrated form. The conclusions reached are that titaniferous ores present no extraordinary difficulties in the way of reduction and impose no special strain on the furnace or its linings. The metals in the original ore were as follows:—

	Per Cent.
Chromium	0·112
Vanadium	0·200
Manganese	0·260
Titanium	12·610
Iron	47·470
Nickel	trace

The phosphorus amounted to 0·018 per cent. In the concentrated products the iron was between 55·95 and 56·47 per cent., and the titanium 11·80 to 11·83 per cent. With one-eighth of titaniferous ore in the burden the following pig irons were obtained:—

	1	2	3	4	5
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silicon	2·00	1·85	2·50	3·00	2·70
Sulphur	0·027	0·035	0·021	0·021	0·015
Phosphorus	0·632	0·609	0·62	0·642	0·65
Manganese	0·44	0·48	0·50	0·41	0·32
Titanium	0·494	0·50	0·595	0·569	0·599
Vanadium	0·058	0·062	0·067	0·075	0·069
Graphite	3·28	3·23	3·39	3·57	3·47
Combined carbon	0·51	0·54	0·37	0·25	0·23
Total carbon	3·79	3·77	3·76	3·82	3·70
Chromium	0·038	0·035	0·039	0·036	0·038

Analyses of the slags obtained are also given. The titanium ranged from 2·7 per cent. to 4·65 per cent. With varying proportions of ore in the burden a wide range of pig irons was obtained. While smelting, the tendency previously observed with the particular furnace, to hang and slip, was checked and working became very uniform. The pig iron was tough and gave excellent results in foundry mixtures. The breaking point was 50 pounds greater than in cases of pig iron not containing titanium. Photomicrographs of sections of the pig iron produced are given.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 721–726, 742*c*.

Smelting of Vanadiferous Ores.—B. de Alzugaray[1] deals with the direct production of ferro-vanadium alloys. A difficulty to be met with in the direct treatment of vanadiferous iron ores, owing to the peculiar properties of vanadium, and also titanium, is that the greater portion of both elements pass into the slag forming silicated compounds, while another portion is separated as carbon-nitrogen compounds, which also mix with the slag. These difficulties have been successfully solved by the author, who produced cast-iron and steel-alloys with vanadium and titanium, in a direct way from the treatment of iron ores in which these elements were present, recovering almost the whole of these metals from the ore. By direct reduction of Norwegian magnetites, a cast iron was obtained, having the following composition:—

	Per Cent.
Carbon	3·28
Silicon	2·60
Sulphur	0·05
Phosphorus	0·04
Titanium	3·03
Vanadium	0·35
Manganese	0·60
Iron	89·95

From this iron basic open-hearth steel of the following composition was made:—

	Per Cent.
Iron	98·620
Carbon	0·180
Silicon	0·100
Sulphur	0·030
Phosphorus	0·020
Titanium	0·120
Vanadium	0·230
Manganese	0·700

Removal of Scaffolds in Blast-Furnaces by Shot-firing.—H. Schöneweg[2] gives an account of his experience in the removal of scaffolds in blast-furnaces by means of shot-firing. He uses a 2¾ inch steel tube about 8 feet long, one end of which is closed, and into this is inserted a 2-inch tube of the same length. The charge is placed in the inner tube and a small hole is bored at about 3 feet from its open end through which the fuse is inserted. One end of the inner tube is closed with a wood plug, the charge, for which any safety explosive may be used, is run in and the empty space above the charge is filled out with sand. The upper end of the tube is then plugged with clay. The larger tube is first introduced empty through a hole in the furnace wall, and the loaded inner tube is then inserted and the charge exploded. Care should be taken that the charge is at least 12 inches distant from the brickwork, at its nearest point. A number of cases are quoted where a few shots fired inside the furnace have been effective in breaking down obstructions. The same apparatus and method are described elsewhere.[1] In this type of gun all the safe handling explosives can be used in either powdered or gelatinous form. In France and Belgium, cheddite, macarite, and sabulite have been used with success.

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[1] *Mining and Engineering World*, 1914, vol. xli. pp. 989-990.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1333-1336.

Cleaning of Blast-Furnace Gases.—The washing and cleaning of blast-furnace gases are dealt with by J. E. Johnson, Jun.,[2] who describes and illustrates several leading types of machinery for this purpose on the market. The general principles underlying the problem are first explained and the detailed descriptions of cleaning appliances follows. They comprise early forms of dust catchers; the Steese and Ford washer; the Mullen washer; and the Brassert-Witting whirler. The relative merits of dry and wet cleaning are discussed, and in this connection the Dyblie whirler; the Zschocke system; the Duquesne spray tower; the Bian washer; the Theisen washer; the Schwarz-Bayer disintegrator washer; the Fowler and Medley vertical gas washer; the Feld washer; the Reco centrifugal washer; the Sepulchre washer; and the Halberger-Beth gas cleaner, are each in turn illustrated and described. The use of the kapnograph for indicating the degree to which cleansing has been effected is also explained.

Measurement of Gases.—E. Stach[3] describes and illustrates some modern appliances for the measurement of the pressure, velocity, density and composition of gases. In particular the Thomas recording meter, made by the Pintsch Company, is dealt with, the accuracy of which is said to be within 1 to 2 per cent.

The Kapnograph, or Dust Recorder.—E. K. H. Borchers[4] describes the principle of his patent "kapnograph," or dust recorder, for registering a visible permanent record of the dust content of waste gases. The apparatus is illustrated in section. A stream of gas at constant velocity is made to impinge through a nozzle upon a specially treated recording paper carried on a slowly revolving cylinder. The dust clings to the surface, and the mark produced on the paper is of such a distinctive character that the dust contents of the gas can be estimated with fair accuracy by comparing the record with a standard scale.

Hot-Blast Stoves.—B. Osann[5] refers to the recently established fact that hot-blast stoves attain their highest efficiency when the air and gas are driven through at high velocity. A method of calculating the dimensions of stoves based on given velocities of the gas is given.

O. Simmersbach[6] describes various modern types of blast-furnace stoves, and in particular reviews the investigations of A. N. Diehl on the heat balances and efficiencies of stoves of different construction. Diehl's results, showing the efficiency of stoves using cleaned and uncleaned gas, are republished.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 115.

[2] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 685–692, 760–769.

[3] *Glückauf*, 1914, vol. l. pp. 1233–1238.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1346–1348.

[5] *Ibid.*, pp. 1569–1575.

[6] *Ibid.*, pp. 1873–1881.

J. E. Johnson, Jun.,[1] sketches the evolution of the blast-furnace stove from the earliest experiments of Neilson to those of Sir William Whitwell, and describes the two classes of stove now in vogue—the iron pipe stove and the fire-brick stove. The following modifications of the latter are also described: the three-pass central combustion chamber stove; the M'Clure stove; the Roberts three-pass stove; and several varieties of the two-pass stove. Illustrations are also given of various designs of stove burners and of chimney valves, stacks and domes. The question of the equalisation of the blast temperature and the calculation of the size and heating surface of stoves is also discussed, tables being given showing heat losses in stove practice due to inefficient combustion of fuel gas. Recent experiments in Germany by which the heat imparted has been greatly increased by increasing the velocity of the gas through the stoves are also briefly noted. Three stoves with clean gas and high gas velocity may easily be better than four stoves without those advantages, but it is doubtful whether it is advisable to reduce the number of stoves below three until overwhelming proof of the efficiency of this practice is forthcoming.

Blast-Furnace Charging.—A. E. Maccoun,[2] in discussing modern blast-furnace construction, refers to the methods of charging. There are two principal systems used in charging blast-furnaces. The first is known as the Neeland method, in which the stock is run from the bins into round buckets, which are taken to the bottom of the hoist incline and sent up, hanging from a hook. The other system which is used on the majority of furnaces consists of the use of a rectangular skip bucket on wheels, running from a pit beneath the floor of the stock pile up an incline to a hopper above the furnace top.

Handling Appliances at Blast-Furnaces.—J. E. Johnson, Jun.,[3] describes and illustrates the latest and most novel appliances in vogue for handling iron and slag in modern blast-furnace plants. Casting in sand beds has been largely superseded by casting in chills. With iron low in silicon, which has a tendency to attack the chills, the moulds are grouted with clay mixed with water. The functions of the pig breaker are then dealt with, after which various forms of ladle for handling hot metal are illustrated, including the Pollock and the Treadwell hot metal cars, Uehling machines, and the Heyl and Patterson casting machine.

For slag handling a number of special forms of ladle have been designed. Amongst these are the Pollock cinder ladle, the Treadwell ladle, and several forms of slag cranes and grab-bucket systems. For making aggregates the slag is found better suited when it has been allowed to cool slowly. When the slag is crushed methods of magnetic separation often recover profitable quantities of material, particularly in charcoal furnace practice.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 395–411.

[2] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1915, vol. xxx. pp. 935–972.

[3] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 43–50, 85–89.

Mixers.—O. Simmersbach[1] describes the construction and working of a new mixer at the Friedrich-Wilhelms-Hütte, Mülheim. It is intended specially for foundry pig and is of the flat hearth type. The bath measures 11·5 metres long, 3·8 metres wide, and 1·2 metre deep, the capacity being 150 tons.

Ormesby Blast-Furnace's 38 years' Record.—A. O. Cochrane[2] contributes some interesting details as to construction and working of the No. 2 blast-furnace at Ormesby. The furnace began operations in May 1876, and was blown out on 30th May 1914, having produced a total of 1,365,349 tons of pig iron. The dimensions of the furnace were as follows:—Height 90 feet; bosh 28 feet; hearth 8 feet; diameter at nose of tuyeres 6 feet; in June 1880, 7 feet 4 inches; and in 1890, 10 feet. The following table gives details of working:—

	Average Make per Year.	Blast Pressure at Plug-hole.	Coke per Ton of Pig.	Ash in Coke.	Raw Iron Stone.	Swedish Ore.
	Tons.	Lbs.	Cwt.	Per Cent.	Cwt.	Cwt.
1877–1881 .	23,091	3·84	20·43	7·19	66·21	Nil
1882–1886 .	26,932	3·97	19·85	7·81	66·89	,,
1887–1891 .	37,336	4·80	20·12	7·89	68·00	,,
1893–1896 .	41,635	5·01	21·04	8·45	69·32	,,
1897–1901 .	41,122	5·31	20·02	9·27	68·24	,,
1902–1906 .	39,845	5·51	20·29	9·65	67·42	,,
1907–1911 .	42,766	5·60	20·11	11·45	66·08	1·36
1913 . .	41,719	5·55	21·60	11·72	64·76	1·70

There were two bears, an upper and a lower, separated by a layer of kish. The remarkable feature is the relatively small quantity of phosphorus in the centre of each bear, being 0·420 per cent. in the upper and 0·512 in the lower.

Blast-Furnaces in India.—An illustrated description of the iron ore mines, blast-furnaces and steelworks of the Tata Iron and Steel Company, Sakchi, has appeared.[3]

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 305–313.
[2] *Proceedings of the Cleveland Institution of Engineers*, Session 1914–15, pp. 87–89.
[3] *Iron Trade Review*, 1914, vol. lv. pp. 162-167.

Blast-Furnaces in Korea.—It is stated[1] that a new ironworks is to be erected at Kenjiho, near Pyeng Yang, Chosen, Korea. There will be two blast-furnaces, each of a capacity of 150 tons per day. The iron is intended for the steelworks at Wakamatsu to replace that now being imported from China.

Electric Smelting of Iron Ore.—Farup[2] discusses the present position of the electric iron smelting industry, and states that at the present time the position in Norway is briefly that the Hardanger Works, which attempted to smelt iron ore with coke as fuel and by the "Electrometals" process, had proved to be a failure, while the Tinfos Works, where coke also was employed, were giving satisfactory results. In Sweden there were now a number of electric iron smelting furnaces in operation. All these, however, employed charcoal instead of coke, and the annual production was nearly 50,000 tons of pig iron. At the present time the Swedish industry is in a better position in regard to the cost of iron ore, but on the other hand fuel and electrical energy are much cheaper in Norway.

J. Härden[3] summarises and reviews the latest results obtained by Ödqvist[4] at Hardanger in Norway. These results have shown that coke can be used as a reducing agent in furnaces of this type, although the conclusion that this particular design of furnace is fully suitable for working with coke as a reducer should be guarded against. The use of coke has, however, one redeeming feature—the electrode consumption is smaller, probably because the well-conducting coke piled up around the carbons acts partly as secondary electrodes. Against this must be set the drawback arising from the low resistance of the coke, which causes an increase in current and a decrease in voltage, and also alters the zone of reaction.

D. A. Lyon[5] and R. M. Keeney present a report showing the extent to which the electric furnace has been applied to the metallurgy of metals. The electric smelting of iron ore is briefly discussed.

Use of Fluorspar in the Electric Smelting of Ore.—R. M. Keeney[6] reports the results of a series of trials made to ascertain the effect of the use of fluorspar in the electric smelting of iron ore.

Prevention of Accidents in Ironworks.—F. H. Willcox[7] puts forward some suggestions for safety regulations for blast-furnaces.

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[1] *Mining and Engineering World*, 1914, vol. xli. p. 907.

[2] Paper read before the Polytechnic Association, Christiania; *Iron and Coal Trades Review*, 1915, vol. xc. p. 57.

[3] *Metallurgical and Chemical Engineering*, vol. xii. pp. 444–446.

[4] *Teknisk Tidskrift* (*Kemi och Bergsvetenskap*), 1914, vol. xliv. pp. 24–25.

[5] *United States Bureau of Mines*, 1914, *Bulletin* No. 77, pp. 72–101.

[6] *Mining and Scientific Press*, 1914, vol. cix. pp. 335–336.

[7] Paper read before the Pennsylvania Industrial Welfare and Efficiency Congress, September 17–19, 1914; *Mechanical Engineer*, 1914, vol. xxxiv. p. 495.

History of Iron.—Sir R. A. Hadfield[1] briefly reviews the history of the metallurgy of iron and steel, with special reference to the development of manganese steel and of iron-nickel alloys and their various special uses. The lecture was accompanied by an exhibition of specimens and test-pieces, the collection including historical specimens of iron, dating from 125 B.C. down to modern alloy steels for various purposes.

P. Neogi[2] advances evidence, chiefly based on the Rig Veda, of the manufacture of iron in India as far back at least as 2000 B.C. Later, between 500 and 200 B.C., iron appears to have been largely used, more especially for warlike weapons. Probably, however, the most remarkable instance of its employment appears in a medical work describing nearly one hundred surgical instruments used for most delicate operations, which seems to show that the manufacture of steel must have been well understood. From certain burial sites in Tinnevelly iron swords and daggers have been unearthed; but though their exact age cannot be fixed, they are believed to have come down from prehistoric times, and specimens of third-century iron have been recovered from Buddha Gaya.

G. F. Zimmer[3] traces the early history of iron, and shows by means of a diagram the comparative use of copper, iron, and bronze by the ancients.

W. Remy[4] gives an illustrated account of the establishment of the Alfer Ironworks at Alf, on the Moselle. They were founded in 1826 by Ferdinand Remy, after having spent six years in England familiarising himself with puddling and rolling-mill practice. The works were the first in Germany to undertake the puddling of iron and rolling of bar iron.

F. Lange[5] records his reminiscences of a fifty-seven years' career in connection with blast-furnace work, and reviews the developments in blast-furnace practice which he has witnessed in that period.

O. Vogel[6] publishes a short account of the history of the ancient iron industry of Bulgaria.

According to C. E. Godfrey,[7] the first steelworks in America was established at Trenton by Isaac Harrow, on or before September 5, 1734, for the manufacture of various kinds of edge tools. The plant appears to have been in existence as late as 1785.

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[1] Graduates' lecture to the Institution of Mechanical Engineers; *Engineering*, 1915, vol. xcix. p. 195.

[2] Indian Association for the Cultivation of Science, *Bulletin* No. 12, 1914; *Journal of the Royal Society of Arts*, 1914, vol. lxiii. p. 43.

[3] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 14–22, 88–95.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1625–1629.

[5] *Ibid.*, 1915, vol. xxxv. pp. 33–38, 71–77.

[6] *Ibid.*, 1914, vol. xxxiv. pp. 1387–1389.

[7] *Mechanical Engineer*, 1915, vol. xxxv. p. 127.

II.—*BLAST-FURNACE SLAGS.*

Manufacture of Slag Bricks.—The manufacture of bricks from blast-furnace slag is dealt with.[1] The slag to be used must be in fine condition, and this may be brought about either by allowing the molten slag to fall into water or by a dry granulating process. A typical analysis of slag used with success for brick manufacture is as follows: lime, 40 to 44 per cent.; silica, 31 to 33 per cent.; alumina, 20 to 24 per cent.; sundries, 1 to 3 per cent. The simplest and cheapest method of making slag bricks is to mix the granulated slag with hydrated lime in suitable proportions, and then to press the mixture into brick form on a suitable press. The bricks are then either stacked in the open air, where they will gradually harden owing to the setting properties of the mixture; or, if it be desired, steaming at high pressure for eight hours in chambers may be resorted to. Tests made on such bricks after having been stacked in the open air for six to eight weeks gave a crushing strain of 164 to 182 tons per square foot. The steaming process is much used in up-to-date plants with excellent results, tests on bricks subjected to it giving a crushing strain of 60 to 80 tons per square foot, which, after further maturing in the open air for two or three weeks, was increased to 150 to 300 tons per square foot. The manufacture of bricks from dry granulated slag differs from the above only in the fact that the slag must be ground finely, as on this depends entirely the quality of the brick produced. A table is given showing the results of experiments to ascertain the resistance to thrusting stress of a number of bricks.

III.—*DIRECT PROCESSES AND PUDDLING.*

Yields and Wastes in the Puddling Process.—J. E. Fletcher[2] deals with yields and wastes in the puddling process, and considers the possible reactions during the elimination of carbon, silicon, manganese, and phosphorus. The highest yields occur with Northampton and Cleveland pig irons, which, however, make the heaviest demands on the fettling oxides and produce the greatest amount of tap cinder. Refinery iron, cold-blast, and hæmatite irons use the least fettling oxides, produce least cinder, and give lower iron yields than do pig irons of higher phosphorus content.

W. J. Foster,[3] in dealing with the position of the Black Country and its relations to the iron and steel industries, referred to the various sources of supply of raw materials according to the class of iron required. The usual method of excavating the oolitic iron ores of Northamptonshire is illustrated, and the author states that the average cost by hand labour is 11d.; while a machine would perform similar work for 6·5d. Certain economies have been introduced in the fuel consumption required for manufacture of iron. In dealing with the manufacture of wrought iron the author stated that while he was unable to suggest any tangible improvement in the methods of manufacture, it had occurred to him that the puddling furnace might be worked more economically on the regenerator system, which would increase the number of heats in a given time and improve the quality of the product by reason of the high temperatures at the command of the puddler. The mills, &c., should either be electrified or worked direct with gas-engines in a similar manner to steelworks mills.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 301.

[2] Paper read before the Staffordshire Iron and Steel Institute, April 17, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 564–566.

[3] *Ibid.*, April 10, 1915.

Combined Electric and Lancashire Hearths.—G. A. Forsberg [1] gives an account of some preliminary trials made by him of a combination of an electric furnace and a Lancashire hearth. Owing to faulty arrangements the trials were not carried on, but, from the results obtained, the author is confident that in smelting small pig he could effect a saving of at least 10 hectolitres of charcoal per ton. Complete plans of a suggested installation are given.

Direct Process of Iron Manufacture in Brazil.—The direct production of iron in Brazil is described by E. C. Harder.[2] For some time past a small industry has been in operation in the Minas Geraes iron ore district, where a dozen plants exist. The furnaces employed are of two types, (1) closed or crucible furnaces, and (2) open or Italian furnaces. At most plants both types are employed, although the former predominates. They are generally arranged in series of four to eight, and a series of four have dimensions of 4 feet high, 5 feet wide, and 10 feet long. The crucible itself is a vertical cylindrical cavity 2 to 3 feet in depth and a foot in diameter. In the rear wall is a small opening for the admission of the blast, produced by water power. The crucible is filled with alternate layers of charcoal and pulverised iron ore, slightly damped. The charge is ignited and the blast applied. Additional quantities are gradually charged, and the resulting bloom, which consists of intermingled iron, carbon, and slag, weighs about 25 lbs. It is pounded in a trip forge, and often reheated several times to free it from slag. The bars are hammered into strip, from which various small articles are made. Such primitive operations appear to have been in vogue as far back as 1600. Attempts have been made from time to time to introduce blast-furnaces, but with varying success.

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[1] *Bihang till Jernkontorets Annaler*, 1914, pp. 36–38.

[2] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2573-2586.

FOUNDRY PRACTICE.

General Foundry Practice.—T. W. Aitken[1] discusses the difficulties that arise in general foundry practice, classifying them as follows: (1) attributable to the forces of gases and steam; (2) caused by the force of contractions; (3) arising out of the different properties of the various constituents of the mixture.

Practical foundry work is discussed in a series of articles by R. A. Bull,[2] entitled "Making Steel Castings." The subject is arranged and dealt with under the following headings: (1) the converter; (2) the open-hearth and electric furnaces; (3) the pouring of castings generally, and remarks on the relative advantages of basic and acid steel; (4) steel moulding and core making; (5) finishing steel castings, and (6) the testing of castings.

S. G. Smith[3] deals with some problems that arise in foundry practice.

Cupola Construction.—T. W. Aitken[4] indicates some points in the construction of a cupola that are necessary in order to obtain the maximum heat from the combustion of the fuel in the minimum of time, with little or no change in the composition of the metal.

R. Buchanan[5] deals with the origin and development of the foundry cupola.

Details are given[6] showing the effect of the use of a relief valve on the blast-pipe of a cupola.

Cupola Charging.—T. Ehrhardt[7] gives an illustrated description of various types of automatic cupola-charging devices. Some recent installations for the mechanical charging of cupolas are also described in detail by E. Wülfrath.[8] Some excellent illustrations of inclined charging hoists are given. The charging is effected by means of suspended drop-bottom skips, which are introduced through a door in the

[1] Paper read before the British Foundrymen's Association, November 20, 1914; *Foundry Trade Journal*, 1914, vol. xvi. pp. 756–758.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 241–246, 329–335, 358*b*, 375–380, 404*b*.

[3] *Foundry Trade Journal*, 1914, vol. xvi. pp. 701–703.

[4] Paper read before the British Foundrymen's Association, February 26, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 198–199.

[5] Address delivered before the British Foundrymen's Association, February 15, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 156–158.

[6] *Foundry*, 1915, vol. xliii. pp. 26–27; *Mechanical Engineer*, 1915, vol. xxxv. pp. 61–62.

[7] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1281–1286.

[8] *Ibid.*, pp. 1286–1291.

side of the cupola, so that when over the centre of the bed the charge falls vertically into it.

Cupola Practice.—O. D'Asse[1] gives some notes of his experience in cupola working. The effect of alterations in the quantity and pressure of the blast and the height of the melting zone is considered. An interesting practical discussion followed the paper.

R. C. Hogden[2] deals with some points that should be observed in the correct management of cupola operations.

D. Townsend[3] discusses the factors upon which the proper operation of a foundry cupola depends.

R. Moldenke[4] discusses the importance of maintaining the proper height of the fuel-bed in cupolas, in order to secure the maximum temperature in the melting zone.

G. E. Pickup[5] describes the melting of shot iron in the cupola. Over 7000 pounds of shot were charged, and 76·7 per cent. recovered in good castings.

O. Vollenbruck[6] has investigated the behaviour of sulphur in the melting of cast iron in the cupola. Tables of results are given, showing the effect of additions of silicate of calcium and manganese, the influence of the amount of coke and blast, the influence of oxidising flames, and the influence of repeated melting of the iron, all in regard to the content of sulphur.

R. Onions[7] gives some notes on modern iron-founding.

A. Geissel[8] describes experiments made with the object of showing how high-quality castings may be improved and the strength of the metal increased by an admixture of up to 15 per cent. of low carbon pig iron with ordinary foundry iron. His tests show that such an addition raises the tensile strength of the metal by 25 per cent.

The making of grey iron castings is discussed by R. Moldenke,[9] who points out the influence of the various elements on the properties of the resulting casting, and shows the need for careful mixing. The use of moulding machines is also considered.

Specifications for Foundry Pig Iron.—In order to promote uniformity in grading, the American Society for Testing Materials[10] provides that when any one of or all the constituents of pig iron are specified, the following percentages shall be taken as standard:—

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 207–212.

[2] *Foundry*, 1915, vol. xliii. p. 17; *Mechanical Engineer*, 1915, vol. xxxv. p. 193.

[3] Paper read before the Philadelphia Foundrymen's Association, March 3, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 289–290.

[4] *Foundry*, 1915, vol. xliii. p. 28. [5] *Ibid.*, 1914, vol. xlii. pp. 467–468.

[6] *Stahl und Eisen*, 1915, vol. xxxv. pp. 451–453.

[7] Paper read before the Manchester Association of Engineers, February 27, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 190–192, 209–211, 231–232, 247–249.

[8] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1291–1294.

[9] *Iron Trade Review*, 1914, vol. lv. pp. 987–994 and 1014*b*.

[10] *Year-Book of the American Society for Testing Materials*, 1914, pp. 225–227.

Silicon	1·00 – 3·50	(0·25 allowed either way).
Sulphur (max.)	0·04 – 0·10	
Total carbon (min.)	3·00 – 3·80	
Manganese	0·20 – 1·50	(0·20 allowed either way).
Phosphorus	0·20 – 1·50	(0·15 allowed either way).

The standard methods of the American Foundrymen's Association shall be used for analysis, sulphur being determined gravimetrically unless otherwise specified. For market quotations a pig iron containing silicon 2·00 (±0·25) and sulphur 0·05 per cent. (max.) shall be taken as the basis, and a table is suggested to be used for adjusting disputes between buyer and seller, based upon the agreed price for the basis metal and a constant differential to be determined at the time the contract is made.

Influence of Titanium as an Addition in the Cupola.—H. Braune[1] states that experiments carried out at the Royal Technical High School, Stockholm, indicate that the addition of titanium to foundry iron removes nitrogen more readily than it deoxidises. 0·25 per cent. of titanium removes as much nitrogen as larger quantities, without causing any alteration of the transformation point, texture, specific gravity and mechanical character of the iron. An addition of 0·25 per cent. of ferro-titanium increases the tensile strength. The quality of steel also appears to be improved by the addition of 0·25 per cent. of titanium. By embedding iron in 90 per cent. titanium and heating in a cementation furnace for 14 days, it was found that the superficial portions absorbed 0·1 per cent. titanium.

Influence of Steel Additions in the Cupola.—S. Kern[2] states that he has found the method of adding steel in the form of shearings from plates, angles, &c., or runners from steel castings, to the cupola pig iron charge most satisfactory for obtaining castings to stand hydraulic or steam pressure. The author uses pig irons of the following composition:—

	South Russia.	Ural.
	Per Cent.	Per Cent.
Graphite	2·7	3·0
Combined carbon	0·8	1·0
Manganese	0·5	1·5
Silicon (average)	2·7	0·85
Phosphorus	0·1	0·05
Sulphur	0·05	0·05

He melted in a crucible a test charge to contain about 2·15 per cent. of silicon, 3·5 per cent. of total carbon, 0·7 per cent. of combined carbon, and 0·8 per cent. of manganese with steel shearings. The crucible charge comprised:—

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[1] *Jernkontorets Annaler*, 1913, vol. lxviii. pp. 822–854.
[2] *Chemical News*, 1915, vol. cxi. pp. 3, 152–153.

	Per Cent.
South Russia pig iron	70
Ural pig iron	30
	100
Steel, on 100 per cent.	10

The cast specimens gave 12·5 to 12·0 tons per square inch tensile strength, and 1·6 to 1·7 tons for fracture. The bars for the first tests were 2 inches long and ¾ inch diameter, and for the second 12 × 1 × 1 inches. The author states that being satisfied with these results he now makes cupola charges consisting of 70 per cent. of South Russia pig iron, 30 per cent. of Ural pig iron, and 15·0 to 14·5 per cent. of steel runners. The results of tests showed 11·5 to 12·0 tons per square inch tensile strength, and 1·4 to 1·5 tons for fracture. The castings obtained are close-grained, and give good hydraulic tests.

The author states that the product obtained is not what is known as semi-steel, but close-grained cast iron, where the percentage of metallic iron is increased by the addition to the cupola charge of not more than 15 per cent. of wrought iron or steel scrap. By this means the free crystalline graphite in the iron is absorbed by the free iron introduced, and transformed into amorphous graphite. A pig iron from South Russia, containing graphite, 2·20 per cent.; combined carbon, 0·80 per cent.; silicon (average), 1·80 per cent.; manganese, 0·80 per cent.; phosphorus, 0·30 per cent.; and sulphur, 0·07 per cent., gave good results when melted alone with 5 per cent. of steel scrap in the crucible. An addition of 2·5 per cent. of steel scrap was made to the crucible charge, and the following test results were obtained: 10·5 to 11·5 tons per square inch in tensile strength, and 1·3 to 1·4 tons in fracture tests.

Semi-Steel.—Y. A. Dyer[1] describes the method of manufacture of semi-steel and the physical properties of the material as revealed by tests.

I. I. Howell[2] deals with the nature and uses of semi-steel.

Oil-fired Open Furnace for Foundries.—H. Ring[3] gives an illustrated description of a 1-ton open-hearth furnace with tar oil-firing for steel foundry work. The oil used has a specific weight of 1·04 at 15° C. with a flash point above 65°. The heat value is about 8800 calories. According to the nature of the castings required, the charge consists of about 200 kilogrammes of hæmatite, 400 kilogrammes of liquid metal, and 400 kilogrammes of scrap, to which are added 7 kilogrammes of ferro-manganese, and 2 of ferro-silicon. The finished metal has about the following composition:—

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[1] *Manufacturers' Record*, August 6, 1914.

[2] *Foundry Trade Journal*, 1915, vol. xvii. pp. 38–40.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1424–1428.

	Per Cent.
Carbon	0·25
Silicon	0·46
Manganese	0·49
Phosphorus	0·06
Sulphur	0·04

The heat is 2½ hours' duration, and oil consumption per heat is 165 litres, for the charge specified.

Small Converters in Steel Foundry Work.—G. Muntz[1] compares the relative advantages of Tropenas converters and electric furnaces for the manufacture of steel castings. The grade of steel manufactured in the Tropenas converter can, even in the hands of an inexperienced steel-man, be safely relied upon for quality. On the other hand, the electric process, like the open-hearth and other methods, entails the use of closed furnaces, in which no outward signs are in evidence when the steel has reached a suitable composition. Test-bars have to be secured at intervals and the quality of the steel determined in various ways. The personal equation therefore plays an important part, and expert melters are scarce and command high salaries. The phosphorus and sulphur contents certainly do not increase in the electric furnace, but so far as steel castings are concerned, these two elements are not of great importance. The carbon, however, which is of importance, cannot be controlled as easily as in the Tropenas converter, where the operation can always be stopped at the proper time and absolute uniformity realised. Converter steel, while higher in phosphorus than electric steel, can easily be brought within the ordinary limits of safety.

I. Rennerfelt[2] discusses the use of the electric arc furnace in connection with the manufacture of steel castings, and criticises the views expressed by G. Muntz.[3] Although by no means "foolproof," the electric furnace in proper hands gives excellent and most reliable results, is easily managed, and should be an important adjunct to the steel-casting industry.

The manufacture of large castings in steel foundries having small converters is described.[4] At the Fonderia Milanesa di Acciaio at Milan several heats are combined, the first blown heats being held in the ladle under a covering of slag until the required weight is reached. A whole series of heats can be combined if a mixer is used that is well preheated. The steel-making capacity of this plant consists of three 1-ton converters, two open-hearth furnaces of 3 to 4 tons, one open-hearth furnace of 6 tons, and a Stassano electric furnace holding about 1 ton. Only one converter can be blown at a time, owing to insufficient blast, so that as fast as one is turned down another is turned up. Also only two open-hearth furnaces can be run together.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 379–381.

[2] *Ibid.*, pp. 581-583.

[3] *Ibid.*, pp. 379–381.

[4] *Iron and Coal Trades Review*, 1915, vol. xc. p. 505.

Electric Furnaces in Steel Foundry Work.—W. G. Kranz[1] gives details of the behaviour of a Heroult furnace for the manufacture of steel for castings. The advantages of using such steel are absence of segregation, elimination of oxides, and general uniformity of composition, together with almost entire elimination of sulphur and the complete control of the other elements. Such steel also possesses greater tenacity, a high ratio of elastic limit to ultimate strength, responds readily to heat treatment, and gives perfect control of pouring temperature, so that light and intricate shapes can readily be cast by using very hot metal.

G. Muntz[2] points out the limitations of the electric furnace in the manufacture of steel castings. Considerations of the cost of working, energy consumption and other circumstances show that although the electric furnace can carry refining to a high stage of excellence, this is not always necessary in producing castings, and other methods and processes such as, for example, the Tropenas give as good results more economically. Steel castings from electric furnaces would appear therefore to be limited to such special work as cannot satisfactorily be carried out in other furnaces.

C. H. Hansen[3] discusses the manufacture of electric steel castings. They are usually made with the lower carbon content, and can be made when melting in clay-lined crucibles. As the result, the castings do not necessarily require to be annealed, although this treatment tends to improve them. Although much stress has been laid on the economy attaching to continuous operation of the electric furnace as compared with mere day-shift operation, the relative efficiency of night work and other considerations lead to much of this alleged economy being sacrificed. The pouring of exceedingly hot steel for castings is advocated. The surface arc type is a better furnace for making castings than its critics allow, but, on the other hand, the submerged arc type is still better owing to its larger capacity and lower cost of operation.

S. Muntz[4] and S. Roubieu discuss difficulties in steel foundry practice and methods by which they may be overcome.

Moulding Sand.—R. W. Stone[5] gives the results of sieve-tests made on American sands for making steel castings. The specifications of the Panama Canal Commission for sand required that it should be sharp silica sand, free from loam and other organic matter, and show on analysis: SiO_2, 95–100 per cent.; Fe_2O_3, under 1 per cent.; CaO, under 1 per cent.; MgO, under 1 per cent.

A. Schmid[6] points out that tests of moulding sand which depend on chemical analysis are often insufficient for a proper judgment of the necessary qualities, and he recommends the following as a good test. Take a good average sample of 1 kilogramme weight, slightly moisten, rub in the hands and mix well. The sample should then be lightly rammed with a glass rod in an unglazed porcelain boat, the surface moistened and smoothed with a spatula or knife blade, and the whole dried rapidly at 150° C. A good sand will become firm and hard, and show no visible change, or at most only a slight shrinkage, while bad sands will shrink considerably and crack. When the sample is thoroughly dry let a drop of water fall on it. In a good porous sand the drop will immediately disappear, but if the water spreads over the surface the sand can be rejected at once. Finally the boat with the sample should be heated quickly in an electric furnace up to 1350° and maintained at that temperature for 15 minutes. A good sand will show scarcely any noticeable skrinkage, and the surface will remain even, fine-grained and dull. Inferior sands show a slightly shiny surface, indicating a tendency to sinter. Bad sands will be quite glazed, and show shrinkage and blistering. The test with the drop of water for porosity is generally sufficiently determinate of the suitability of the sand.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 927–930.

[2] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 108–110.

[3] Paper read before the American Electro-chemical Society; *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 335–336.

[4] Steel Castings; *Mechanical Engineer*, 1915, vol. xxxv. pp. 409–411.

[5] *Foundry Trade Journal*, 1914, vol. xvi. p. 652.

[6] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1428–1430.

Preparation of Moulding Sand.—C. Henning[1] describes a large installation for the preparation of moulding sand, recently put in operation in a German foundry. It is capable of handling 3 cubic metres of sand per hour.

A. M. Thompson[2] deals with the economical manipulation of foundry sand.

Moulding.—The relative advantages of dry and green sand castings are compared by P. R. Ramp.[3] Castings of any size may be made in dry sand, and the advantages of dry sand over skin-dried moulds are almost as great as those of dry sand moulds over green sand moulds. Large castings are often both cheaper and better when made in dry sand than green sand or loam work. The need for careful ramming is specially noted.

H. Becker[4] describes in detail the method of moulding in sand by means of a pattern and templates of a heavy bed-plate for a machine tool. The calculated weight of the casting was 86 tons.

J. G. Robinson[5] describes and illustrates the preparation of a mould for a fly-wheel by the use of strickle-boards and core boxes.

Moulding Machines.—The Taunton jarring moulding machine, worked by compressed air at 80 to 100 lbs. pressure, is illustrated and described.[1] The ramming of the sand is performed by a jarring action, but the impact being made in mid-air no vibration is transmitted from the machine to the foundry floor. The machine has been brought out by Rudman, Lancey and Craven, of Taunton.

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[1] *Giesserei Zeitung*, 1914, vol. xi. pp. 617–622.

[2] Paper read before the Chicago Foundrymen's Club; *Foundry Trade Journal*, 1914, vol. xvi. p. 655.

[3] *Iron Age*, 1914, vol. xciv. pp. 534–535.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1841–1848.

[5] Paper read before the British Foundrymen's Association, November 14, 1914; *Foundry Trade Journal*, 1914, vol. xvi. pp. 763–766.

The Osborn direct-draw roll-over jolt moulding machine is described and illustrated.[2] It can take boxes up to 48 × 66 inches with a maximum pattern draught of 24 inches, and it is specially adapted for work of a complicated nature such as crank cases and cylinders.

A heavy duty combination moulding machine designed to perform all the operations connected with making a mould is described and illustrated.[3]

The Pridmore moulding machine, which combines electrically driven jar-ramming, and the pneumatic rock-over drop machine are also illustrated and described.[4]

R. Pradel[5] describes and illustrates a new type of moulding machine operated by electricity. A travelling sand-mixing machine is also described.

Foundry Cores.—J. Shepherd[6] discusses the disadvantages of oil-sand cores, that is, cores made of silica sand with an oil-binder.

Drying Stoves.—T. McFarlane[7] describes and illustrates the use of producer-gas for drying purposes in the foundry.

W. N. Best[8] describes the use of oil as fuel in mould and core-drying ovens, and in brass foundry practice.

Large Castings.—J. Leber[9] presents some technical considerations in the moulding, mixing of metal, and pouring of large castings and castings of complicated design.

The casting of a large shear housing at the works of the Hubbard Steel Foundry Co., East Chicago, Indiana, is described.[10] The casting weighed 70 tons, and was made with steel from two open-hearth furnaces of only 30 and 35 tons capacity each.

Pipe Founding.—A. Midgley[11] deals with the manufacture of various kinds of cast-iron pipes, and the methods adopted for preparing the patterns.

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[1] *Engineer*, 1915, vol. cxix. pp. 189–190.

[2] *Ibid.*, p. 261.

[3] *Iron Trade Review*, 1914, vol. lv. p. 385.

[4] *Ibid.*, p. 431.

[5] *Giesserei Zeitung*, 1914, vol. xi. pp. 487–490.

[6] *Foundry Trade Journal*, 1915, vol. xvii. p. 195.

[7] Paper read before the British Foundrymen's Association, February 27, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 185–189.

[8] Address delivered before the Newark Foundrymen's Association; *Mechanical Engineer*, 1915, vol. xxxv. p. 353.

[9] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1521–1525.

[10] *Iron Trade Review*, 1914, vol. lv. p. 436.

[11] Lecture delivered before the British Foundrymen's Association, January, 20, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 153–154.

Malleable Iron Castings.—H. O. Slater[1] discusses some practical aspects of the subject of the manufacture of malleable iron castings.

R. Moldenke[2] gives an account of the manufacture of malleable castings, dealing, in detail, with the composition of the white iron employed, the annealing process and the melting process. The character of the carbon in the annealed castings is then described, and certain troubles encountered in making malleable castings, such as excessive shrinkage, are dealt with, as well as the precautions to be observed in the melting process.

The galvanising of malleable castings, including their cleaning, pickling, and coating, is dealt with by E. Touceda.[3]

The various types of melting furnaces for use in the manufacture of malleable cast iron are dealt with.[4]

Sand-Blasting.—R. H. Parsons,[5] in discussing the question of safety in sand-blasting, describes a novel installation which dispenses with the usual method of protecting the operator by a hood over the head.

Foundry Equipment.—J. Horner[6] describes and illustrates various types of foundry cranes, hoist and overhead transport arrangement in foundries.

A. Gradenwitz[7] gives details as to the installation and application of telpherage systems in large foundries in Germany. They are operated electrically and work automatically. The Bleichert system or one of its modifications is usually adopted. Illustrations are given of instalments of this nature, both in France and in Germany.

C. E. Clewell[8] deals with the use of lifting magnets, and the cost of operations where they are employed.

E. Munk[9] discusses the heating, ventilating, and lighting of foundries. Central heating systems are advocated, and for the ventilation of foundry sheds, fans blow in a supply of fresh air, while in the subsidiary departments a suction system is adopted for the removal of the foul and dust-laden air.

Recovery of Scrap Iron from Sand in Foundries.—E. Oppen[10] describes a travelling magnetic separator for recovering small scraps of iron from sand and sweepings in foundries. A foundry in Saarbrücken, with an output of 500 tons of castings monthly, claims to be recovering 30 tons of iron per month, which represents a net saving of £450 a year.

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[1] Paper read before the British Foundrymen's Association, January 22, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 84–86.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 857–861, 911–914, and 930*b*.

[3] *Ibid.*, pp. 1137–1138.

[4] *Foundry Trade Journal*, 1915, vol. xvii. pp. 94–98.

[5] *Electric Railway Journal; Foundry Trade Journal*, 1915, vol. xvii. p. 155.

[6] *Engineering*, 1914, vol. xcviii. pp. 720–723.

[7] *Iron Trade Review*, 1914, vol. lv. pp. 295–301.

[8] *American Machinist*, 1914, vol. xli. pp. 587–592.

[9] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1069–1074, 1294–1299.

[10] *Ibid.*, p. 1532.

British Steel Foundry.—An illustrated description is given [1] of the equipment of the Carntyne foundry of Steel Castings, Limited, at Parkhead. The works are designed for the production of steel castings up to ten tons. Although hand-moulding is almost exclusively adopted, there is a Stewart wheel-moulding machine installed, upon which wheels can be moulded from 1 foot up to 16 feet in diameter, and of any breadth up to 42 inches. The open-hearth furnace is of the latest type, with exceptionally deep chambers. Gas is supplied by two Smith-Wincott water-sealed producers.

German Foundries.—An illustrated description is published [2] of the extensive iron foundries of Sulzer Brothers, at Ludwigshafen, on the Rhine. The works are well laid out and equipped with every modern appliance for an annual output of 12,000 tons of iron castings, and 250 tons of brass.

Swiss Foundries.—W. Ahrens [3] describes and illustrates the pattern-making workshops and pattern store of the Sulzer Company at Winterthur.

American Foundries.—The plant and accessories of the Seattle Electric Steel Foundry, where a Girod furnace of 60-cycle, single-phase 13,000 volt type has been installed for making castings, are described and illustrated by F. A. Churchill, Jun.[4]

A description is given by M. R. Kavanaugh [5] of the layout of the foundry of the Studebaker Corporation at South Bend, Indiana, for the manufacture of grey iron castings.

B. Keller [6] has published a report on American foundry practice, compiled from observations made during a recent visit to various typical American foundries. Illustrated descriptions are given of cupola charging apparatus and sand-mixing machinery.

Foundry Economics.—F. A. Parkhurst [7] deals with the operation of foundries on a scientific basis, and gives a detailed description of how time studies are made in American foundries.

The value of scientific management in foundry practice, and the economy resulting in the introduction of a well-thought-out scheme of bonus wage payments, with the bookkeeping incidental thereto, is described.[8]

A table is given [9] showing the total number, and the number classified by products, of the foundries in the United States and Canada in 1914.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 55–56.

[2] *Stahl und Eisen*, 1915, vol. xxxv. pp. 441–445.

[3] *Ibid.*, 1914, vol. xxxiv. pp. 1526–1530, 1652–1656.

[4] *Iron Trade Review*, 1914, vol. lv. pp. 1043–1045 and 1050.

[5] *Steel and Iron*, 1915, vol. xlix. pp. 366–368.

[6] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1418–1424.

[7] *Foundry*, 1915, vol. xliii. pp. 21–26.

[8] *Iron Age*, 1914, vol. xciv. pp. 523–531.

[9] Foundry; *Foundry Trade Journal*, 1914, vol. xvi. p. 695.

PRODUCTION OF STEEL.

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I.—*PROCESSES OF STEEL PRODUCTION.*

Crucible Furnaces.—Particulars are given [1] of the crucible furnace in operation at the Pittsburgh works of the Metro Steel Company. This installation is claimed to be among the first to use powdered coal for melting crucible steel commercially in America. The capacity of the furnace is ten standard pots in a single hole, with five covers. It will melt in from 3½ to 4½ hours.

Some modern types of crucible steel melting furnaces are described [2] and illustrated.

F. C. Barker,[3] in dealing with coke and oil-fired crucible furnaces, compares, in the former class, the working of the Morgan tilting furnace, and "M.R.V." tilting furnace, while in the latter class he compares the Morgan and the Buess furnaces.

Duplex Process.—F. F. Lines[4] describes the mode of carrying out the duplex process of steel manufacture at the Maryland steel-works. It involves a combination of an acid-lined converter with a basic open-hearth furnace, and, of the two alternative methods of blowing, the system under which the converter metal is completely desiliconised and the carbon blown down to about 0·10 per cent. is adopted. This method commends itself on account of the regularity of the carbon content of the metal going into the open-hearth furnace, and in certain cases by the more complete removal of other constituents. The metal from a number of blows is collected in one ladle, in order to supply sufficient for an entire open-hearth heat, and although this requires larger crane capacity, it has the advantage of reducing the charging of the furnace to one operation. Five 50-ton tilting furnaces are used, each furnace being emptied on each heat. A plan of the works showing the arrangement of the different parts is given. There is an electrically operated metal mixer of 1000 tons capacity, the mixer being gas-fired and the consumption being 100,000 cubic feet of gas in 24 hours. The mixture has a 9-inch magnesite lining, backed up by 13 inches of fireclay brick. Three converters of the concentric type and of 18 tons rated capacity are employed, but 20 to 22 tons of metal have been repeatedly blown. The blown metal is received in a 60-ton transfer ladle. The open-hearth department is supplied with producer-gas from nine self-cleaning Hughes producers, but, for a period in 1913, owing to a depression in trade and the necessity for operating the plant five days per week, oil was substituted for gas, and it was found that the furnaces could be brought to a proper temperature with oil more quickly than with gas and at somewhat lower expense. One of the furnaces was therefore remodelled to burn oil. For the working of the metal itself, three fully blown converter charges are poured into one transfer ladle, with or without the addition of iron in the ladle for carbon. The converter charge is made up of 75 per cent. of mixer metal and 25 per cent. of cupola metal, the latter being a mixture of 70 per cent. pig iron and 30 per cent. of rough steel-scrap. As soon as the converter charges are blown, they are taken to the open-hearth and poured in, a mixture of 1 to 2 per cent. of burnt lime and 1¼ per cent. of roll-scale having previously been placed on the bottom of the furnace. The time elapsing between tapping one heat and charging the next varies from 20 to 60 minutes. As soon as the duplex metal is in the furnace, it is tested for carbon. Several alternative methods of treatment in the open-hearth furnace are described, modifications having been introduced from time to time to meet certain practical difficulties, such as the skulling of the metal in the transfer ladle and the boiling out of carbon before tapping, which necessitates further recarburising. With the practice now adopted, the maximum daily production has averaged 620 tons per furnace. The average working-time of three furnaces during a run of three years has been 5½ days per week, and it may be said, with the furnaces duplexing exclusively, they will give 500 to 600 heats to a roof, and from 150 to 200 heats to a front. 250,000 tons of duplex steel have been used for making rails, and their behaviour has been compared with that of 125,000 tons of ordinary open-hearth steel. The result of the observations has shown that there was no difference in the quality of the two products.

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[1] *Steel and Iron*, 1915, vol. xlix. p. 9.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1635–1636.

[3] Paper read before the British Foundrymen's Association, February 26, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 199–201.

[4] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 679–694.

The new duplexing department of the Pennsylvania Steel Company at Steelton, Pennsylvania, is described.[1] It consists of a plant of converters and tilting open-hearth furnaces. There are two 25-ton acid-lined Bessemer converters, a 400-ton and an 800-ton mixer, and six 90-ton basic-lined stationary open-hearth furnaces, besides two 200-ton Campbell-type tilting open-hearth furnaces, likewise basic-lined. The open-hearth department is supplied with six Hughes 10-foot mechanically-stoked producers for the two tilting furnaces, and a further battery of fifteen similar producers for the fixed furnaces.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 531–536.

Illustrated descriptions of a number of plants in America manufacturing steel by the duplex process are given by J. K. Furst.[1] With one exception, the firms concerned combine the acid Bessemer with the basic open-hearth process. The exception is the Dominion Iron and Steel Company of Canada, where the process involves the use of basic Bessemer and basic open-hearth. The first plant described is that of the Tennessee Coal, Iron and Railroad Company at Ensley, where duplexing on a large scale was for the first time attempted in America. Two 20-ton converters are used, and the iron is taken from mixers. After blowing it is poured into a 20-ton ladle and taken to the open-hearth furnaces, which have a capacity of 100 tons, and are of the tilting type. The converter house being situated between two batteries of open-hearth furnaces, the journey of the blown metal is reduced as much as possible. The chemical aspects of the process at these works are as follows: the pig contains 0·80 to 1·25 per cent. of silicon; 0·9 to 1·0 per cent. of phosphorus, and 0·3 to 0·4 per cent. of manganese. The metal is desiliconised, and partly decarburised, in the converter, and four ladles are required for each open-hearth heat, the first two being blown soft (carbon 0·1; phosphorus 0·7 to 1·0, and manganese 0·08 per cent.), and the second two ladles being partly decarburised. Burned lime, iron oxide, and 15 per cent. of scrap are charged into the open-hearth furnace prior to introducing any molten metal, then the first two ladles are added, and finally the last two, whereupon a violent reaction takes place, all the phosphorus passing over with the slag. The furnace is tilted, the slag run off, and recarburisation effected when necessary, but usually it is possible to catch the carbon on the way down.

Similar details are given respecting each of the other duplex plants and processes described. They include the plant of the Dominion Iron and Steel Company; the new Saucon plant of the Bethlehem Steel Company, where there is a 1000-ton hot-metal mixer, and where duplexing is estimated to save 65 per cent. of the time formerly taken in working a charge; and the Pennsylvania Steel Company's plant. The introduction of the duplex process has greatly developed Bessemer practice, and modified and improved the plant and helped to solve many problems.

Relative Economy of the Open-hearth and Bessemer Processes.—A translation has appeared of the paper by N. Schock[2] on the relative economy of the open-hearth and basic Bessemer processes in the Minette district.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2493–2514.

[2] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 43–45; *Stahl und Eisen*, 1914, vol. xxxiv. pp. 697–707; *Journal of the Iron and Steel Institute*, 1914, No. I. pp. 671–672.

Action of Fluorspar on Open-hearth Slags.—W. S. Hamilton[1] states that the remarkable fluidity conferred by a small quantity of fluorspar being added to molten slag has suggested that the reaction may be a catalytic one. Reactions which may account for the thinning of a basic slag are shown in the following equations, although no doubt more complex reactions take place. Silica reacts with fluorspar to yield silicon fluoride and calcium silicate:—

$$3SiO_2+2CaF_2=SiF_4+2CaSiO_3.$$

Lime reacts with silicon fluoride to yield fluorspar and calcium silicate:—

$$3CaO+SiF_4=2CaF_2+CaSiO_3.$$

In the first equation the fluorspar reacts with the silica in the slag, giving silicon fluoride (a gas), and calcium silicate, a fusible slag. Part of the silicon fluoride will escape, but a greater part will react with the lime, giving fluorspar again, and more calcium silicate, the fusible slag. The newly formed fluorspar will react with more silica, as in the first equation, and the cycle is repeated till all the silicon fluoride has escaped. In each reaction some silicate of calcium is formed, which is a slag with a low melting point, and the fluorspar has only been an agent to unite the silica and lime, either of which alone is fused with difficulty.

Fluorine Process of Steel Making.—L. Goldmerstein[2] discusses the fluorine process of steel manufacture, which is the outcome of endeavours to find a method for eliminating sulphur and phosphorus from the bath. The compounds of fluorine with these elements are gaseous at bath temperatures, and hence escape rapidly from the bath.

Silico-Manganese as Addition in the Steel Furnace.—The use of silico-manganese as a substitute for ferro-silicon and ferro-manganese is noted.[3] The additions are made in the same way as for the latter materials, but the chilling effect is very much reduced by the use of silico-manganese, and as the manganese is better protected from oxidation, the amount to be added is less than when using ferro-manganese. Silico-manganese is made by the Vargöns Company at Trolhättan, Sweden. Any grade of alloy can be supplied, containing 17 to 50 per cent. silicon, and 73 to 79 per cent. manganese.

Use of High Grade and Low Grade Ferro-Silicon.—A. Smith[4] deals with the use of ferro-silicon in open-hearth practice, and discusses the relative values of the 50 per cent. electrolytic ferro-silicon and the 10 per cent. pig alloy when added in the furnace.

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[1] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 8.
[2] *Iron Trade Review*, 1914, vol. lv. pp. 167 and 182*b*.
[3] *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 355.
[4] *Steel and Iron*, 1915, vol. xlix. pp. 428–429.

Wood Fuel for Open-hearth Furnace.—J. A. Leffler[1] furnishes an account of trials made at Hellefors with the idea of using wood in conjunction with coal as fuel for an open-hearth furnace. The wood used was the "ribber" or waste from the saw-mill, together with small tree tops. Three periods of trial were taken and the following results obtained:—

	1	2	3
	Kilogrammes.	Kilogrammes.	Kilogrammes.
Coal	32·70	43·06	24·94
Tops	19·98	37·60	15·46
"Ribber"	...	42·11	65·51
Steel produced	155·25	224·47	129·90
	£ s. d.	£ s. d.	£ s. d.
Cost per ton	0 7 10	0 9 0	0 10 5

The author points out that the poor results of (2) and (3) were partly owing to the unseasoned condition of the new tops. It is evident that this system could only be economical where the refuse wood can be had gratis and coal is dear.

Open-hearth Furnace Ports.—The design of ports for open-hearth furnaces, and the position and size of the air and gas supplies giving the best efficiency when using gas or oil as fuel, are discussed by H. F. Miller, Jun.[2] The object to be arrived at is the union of the gas and air at a high rate of speed, and the direction of the flame down on to the charge so that it at no time scatters towards the side walls and roof, and so that the heating be effected by contact rather than by radiation. Diagrams showing how this may be done are given.

Repairing Open-hearth Furnaces.—Mention is made[3] of a system introduced by the Clyde Furnace Company of repairing and maintaining the blocks and ports of open-hearth furnaces without alteration to the existing construction.

Reversing Valves for Open-hearth Furnaces.—A new type of gas and air reversing valve for open-hearth furnaces is illustrated and described by Schömburg.[4]

Electric Refining of Steel.—V. Stobie[5] deals with the manufacture of steel in the Stobie electric furnace. The Stobie furnace, used in connection with a basic open-hearth furnace, promotes the production of steels higher in quality than acid open-hearth steel at a lower cost price than the latter. For example, molten steel of a very ordinary quality from a basic open-hearth furnace, treated in an electric furnace would be equal in composition to acid steel made from the finest Swedish material, would be sounder than the latter, and would give greater yield from the ingot; whilst the cost price would not be increased by more than 9s. 6d. per ton. The author has obtained regularly yields of 93 and 94 per cent. of sound billets from ingots of carbon steels, the balance being composed roughly of 2 per cent. furnace loss and 4 per cent. scrap. If the extra yield of sound material represented a 10 per cent. improvement on some existing practice, the saving might be taken as equivalent roughly to 8s. per ton. This saving must be deducted from the extra cost of electrically heating the open-hearth steel in the Stobie furnace, and gave a net extra cost of 1s. 6d. per ton for the finished electric steel billets.

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[1] *Bihang till Jernkontorets Annaler*, 1914, pp. 643–648.
[2] *Iron Age*, 1914, vol. xciv. pp. 554–555.
[3] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 634.
[4] *Giesserei Zeitung*, 1914, vol. xi. pp. 525–528.
[5] *Proceedings of the Cleveland Institution of Engineers, Session* 1914–15, pp. 101–126.

It is stated[1] that at the Stavanger Electro-Staalverk A. S., Jorpeland, Norway, scrap steel is melted by producer-gas in a 4-ton open-hearth furnace. In about four hours the melted steel is transferred to a Röchling-Rodenhauser induction electric furnace and refined. The composition of the steel is as follows:—

	Open-Hearth, per Cent.	Electric, per Cent.
Phosphorus	0·07	0·023 to 0·010
Sulphur	0·03	0·018 to 0·008
Carbon	0·10 to 0·15	As desired.

F. T. Snyder[2] deals with the application of electric heat to the manufacture of steel generally, and discusses the various types and relative advantages of the leading makes of electric furnaces. Such considerations as the shape, lining, shell, refractories used, power available, and nature of charge are discussed separately.

Manufacture of Ferro-Alloys in the Electric Furnace.—R. M. Keeney[3] gives an account of the development of the manufacture of ferro-alloys in the electric furnace. He describes some types of furnaces used in ferro-alloy production, and also several European plants making ferro-alloys.

S. H. Dolbear[4] reviews the uses of manganese, especially in ferro-alloys, and describes the experiments of the Noble Electric Steel Company of California.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 400.

[2] *Iron Trade Review*, 1914, vol. lv. pp. 1077–1082 and 1110*b*; 1127–1130 and 1154*b*.

[3] *United States Bureau of Mines*, 1914, *Bulletin* No. 77, pp. 102–185.

[4] *Mining Press*, 1915, vol. cx. p. 172.

Manufacture of Ferro-Silicon in the Electric Furnace.—J. Härden[1] gives some historical data and reviews the present methods of manufacturing ferro-silicon. He also gives a brief résumé of a series of tests carried out by M. von Schwarz[2] on the physical properties of ferro-silicon. The modern silicon furnace is very simple in design, and consists, as a rule, of a round or oblong tank of mild steel, the sides of which are subdivided by means of insulating packing so as to prevent a low power factor. The tank is lined with acid bricks, and the dimensions are such that a portion of the charge freezes at the sides and bottom, forming a natural lining. The furnaces are usually supplied with three-phase current through three electrodes suspended of the furnace body. It is also the usual practice to provide three bottom electrodes, connected together so as to act as the neutral point in a star-connected system. One of the difficulties in the process is that the molten metal very easily penetrates almost everything, and as the heat capacity of the molten mass is very great this percolation goes on until it has produced a block large enough to form a natural wall. Water-cooling, as a rule, is not used except for the carbon-holders, which are often cooled by means of a water jacket or water spiral, especially as the electrodes are often of a considerable size on account of the large power used.

Electric Steel Furnaces of Special Type.—T. D. Robertson[3] describes and illustrates the well-known principal types of induction furnaces and arc furnaces for refining steel, and gives an account of the working of typical charges. The field for the use of such furnaces is also considered.

The design, construction, and working of the Rennerfelt electric furnace are described and illustrated.[4] Owing to the circular form of the vault and the thermal insulation used, this type of furnace is particularly suited for rapid melting with a minimum loss, and it constitutes an important contribution to the apparatus applicable to electro-metallurgical work. Aktiebolaget Elektriska Ugnar of Stockholm has successfully developed this type of furnace.

D. A. Lyon[5] and J. F. Cullen deal at length with the design, construction, and operation of electric furnaces in metallurgical operation.

E. M. Schmelz[6] describes and illustrates an electric furnace for medium temperatures. The furnace is a modification of that of Stassano, with the addition of particular features necessitated by the lower melting temperature of the charge.

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[1] *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 732–733, 770–772.

[2] *Journal of the Iron and Steel Institute*, 1914, No. 1, p. 731.

[3] *Journal of the Institution of Electrical Engineers*, 1915, vol. liii. pp. 533-544; *Engineering*, 1915, vol. xcix. pp. 176–178.

[4] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 400–402.

[5] *United States Bureau of Mines*, 1914; *Bulletin* No. 77, pp. 1–71.

[6] Paper read before the American Institute of Metals; *Foundry Trade Journal*, 1915, vol. xvii. pp. 151–152.

British Steelworks.—Considerable extensions have lately been made at the iron and steel works of Bolckow, Vaughan & Co.[1] New laboratories and power station and an entirely new basic open-hearth steel department have recently been completed, and additional rolling-mills are in course of construction. The plant will ultimately consist of ten 60-ton furnaces and two 400-ton gas-fired mixers. The total output of the completed plant will be about 400,000 tons of ingots per annum. The test-house contains two Buckton testing machines of 100 tons and 50 tons capacity respectively, capable of performing all kinds of tensile, impression, and other tests. In the laboratory a complete metallographic outfit has been installed for microscopical research on iron and steel.

American Steelworks.—C. C. Lynde[2] describes the new steel plant of the Central Steel Company, Massillon, Ohio. There are three 50-ton open-hearth furnaces built, although accommodation provides for twelve. Natural gas is used for fuel, but the furnaces are designed to use either gas or oil. There is also a 100-ton Morgan electric ingot stripper installed.

H. Illies[3] describes and illustrates some modern American steelworks, in particular those of the Edgar Thomson Works and of the Bethlehem Steel Company. A table is given showing the number and size of furnaces installed in the principal works and the number and size of those in course of construction.

Phosphoric Acid Contents of Basic Slag.—A. Jung[4] describes a method for increasing the citric acid solubility of phosphoric acid in basic slags. In 1908 an inquiry showed that the total phosphorus in the phosphate meal from the slag grinding works of Germany and Luxemburg was 17·20 per cent., of which 15·20 per cent. was soluble in citric acid. An agricultural test has shown that out of 100 tons of total phosphoric acid, 88·7 tons are soluble in citric acid. The addition of silica to the slag is practised at some works in order to increase the solubility, but as the results were not satisfactory the Peine Rolling-Mills introduced a stirrer, consisting of a flat blade carried on the end of a vertical spindle. The slag ladle is run underneath the stirrer, sand is added, and the revolving blade is lowered into the ladle. The silica thus becomes well mixed with the slag. It is found that the amount of phosphoric acid soluble in citric acid is increased by 5 per cent. of the total. The stirring apparatus is illustrated.

II.—*CASTING AND TREATMENT OF INGOTS.*

Ingot Moulds.—C. F. Williams[5] gives an account of a new form of mould employed at the works of the Carbon Steel Company, Pittsburgh, for high carbon and special alloy steel ingots. It is known as the Bradford mould, and has an annular chamber at the upper end, in which charcoal or other carbonaceous materials are burned. When cast, loam is thrown on the top of the ingots and charcoal on the top of the loam. The formation of blowholes is greatly reduced by the device described.

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[1] *Engineering*, 1915, vol. xcix. pp. 3–7.

[2] *Steel and Iron*, 1915, vol. xlix. pp. 153–157.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1681–1687, 1710–1715, 1792–1795, 1882–1885.

[4] *Ibid.*, pp. 1593–1594.

[5] *Iron Trade Review*, 1914, vol. lv. p. 765.

Production of Sound Ingots.—Sir R. A. Hadfield[1] deals with the production of sound steel for rails and structural purposes, and describes his research work on the subject. Comparison is also made of ingots produced by the author's method and by the ordinary method, the differences in results being illustrated by photographs.

The production of sound steel ingots and rails by the Hadfield special-feeding process is dealt with by G. K. Burgess[2] and Sir Robert A. Hadfield.

E. Crowe[3] contributes a note explanatory of micrographic sections, illustrating a unique case of honeycombing in steel. This occurred during the teeming of the contents of a ladle into ingot moulds. It was discovered that the stopper hole of the ladle was blocked, and all efforts to clear the hole were fruitless. In the meantime the steel had set on the top, sides, and bottom of the ladle to the extent of about 4 inches to 6 inches at the top and 1½ inches on the sides. The ladle was in this condition turned over, and the whole of the liquid steel ran out through the hole in the top crust left by the stopper rod. On cutting up the skull it was found that the underside of the top crust presented, over practically the whole surface, a remarkable honeycombed appearance. The process by which these honeycombs were formed is indicated by means of diagrams. Gases being given off at various points, on the underside of the top crust would form independent bubbles, round which the steel gradually grew. The size of the holes would therefore depend upon the quantity of gases disengaged at any one point. It is obvious also that when the quantity of gas given off at any part became greater than was sufficient to fill the holes, the surplus would overflow and form larger bubbles, covering up some of the smaller ones. That this occurred is shown in the diagrams, for the small blowholes are in hollows, and round the hollows are large blowholes. It is also obvious that such large honeycombing cannot develop on the sides or bottom of the ladle, as the gas would escape and float upwards as soon as liberated.

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[1] *Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 119-140.

[2] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 455–468. See also this *Journal*, p. 40.

[3] *Proceedings of the Cleveland Institution of Engineers; Session* 1914–15, pp. 89–90.

FORGING AND ROLLING-MILL PRACTICE.

Forging Presses.—A 2000-ton forging press, built by Davy Brothers, of Sheffield, for slabbing and punching steel tyres, is illustrated and described.[1]

Drop Hammers for Forging.—An illustrated description is given [2] of a battery of friction drop hammers recently supplied to the Greenock Torpedo Factory by Breet's Patent Lifter Company, Limited, of Coventry. The control of the hammer is entirely by slip, and the arrangement allows of lubricant being applied to the frictional parts in contact. The battery in question consists of three hammers of 40, 15, and 5 cwts. respectively, all operated from an overhead shaft, driven by an electric motor. The power required to drive the hammers when lifting is 76 horse-power, 28 horse-power, and 8 horse-power for the three sizes.

Rolling-Mill Engines.—K. Nibecker[3] describes a twin tandem compound reversing engine driving a 44-inch reversing blooming mill when rolling 20 × 22-inch ingots. He outlines the methods used in testing the engine, and assumptions made in determining the power and steam consumption for the mill. He also considers the steam consumption per unit of metal rolled and the power losses involved. The engine is operated condensing, using steam at 140 lbs. gauge pressure at the throttle valve, and exhausting into a 28-inch vacuum. It is direct connected to the mill, but separated from it by means of a brick wall. Of the total available work 34·5 per cent. is consumed in accelerating and retarding the rotating and reciprocating parts, 9·8 per cent. is used in friction, and only 55·7 per cent. is actually consumed in deforming the steel. The steam consumed per indicated horse-power hour was found to have a maximum value of 23·6 lbs. per cent. after adding the 30 per cent. for condensation, leakage, &c. The engine can change from a speed of 60 revolutions per minute in one direction to 30 revolutions per minute in the opposite direction in less than 2½ seconds. During one month of operation the steam consumption of this mill was 473 lbs. per ton of steel rolled, both on 24-hour runs and for individual ingots.

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[1] *Engineer*, 1914, vol. cxviii. p. 539.

[2] *Engineering*, 1914, vol. xcviii. p. 612.

[3] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1914, vol. xxx. pp. 533–640.

J. D. Berg[1] describes a low-pressure steam-turbine installation for driving two stands of 18-inch three-high rolling-mills of the Carpenter Steel Company at Reading, Pa. The turbine is of the De Laval multistage impulse type. The turbine shaft operates at a speed of 5000 revolutions per minute.

The application of large straight-flow steam-engines in metallurgical practice is discussed.[2] Among the many advantages of this type of steam-engine are its reliability, low steam consumption, and ability to carry large overloads. Particulars are given, by means of a table, of the application of these engines for driving rolling-mills in Germany. Extra large engines have been installed at the Röchling Steelworks and at the Westphalian Steelworks. The one at the Röchling Works has been put in to take the place of the tandem engine for driving a beam and rail mill. It is of 4000 to 6000 horsepower, with 110 revolutions per minute. It operates with a steam-pressure of eight atmospheres.

E. Zix[3] also describes the installation of a straight flow steam-engine of 700 to 1000 horse-power, for driving rolling-mills in a German works.

Particulars are given[4] of a test recently carried out on the new reversing blooming mill engine at the plant of the Brier Hill Steel Co., Youngstown, Ohio. The engine is of the twin tandem compound type, having 44-inch high-pressure and 76-inch low-pressure cylinders with a 60-inch stroke.

Control of Rolling-Mill Motors.—W. Sykes[5] and G. E. Stoltz deal with the control of rolling-mill motors, and with the need for providing a type of control which will make it impossible for a careless operator to injure the apparatus. An important feature of any regulator is the rapidity with which it responds to momentary peak loads. If no flywheel effects were available, the load would approach the theoretical conditions. The amount by which these peaks are reduced depends on the character of the control, and the regulator must respond almost instantly, in order to catch the peak as the metal enters the rolls.

Electrically-driven Rolling-Mills.—A. Dyckerhoff[6] deals with the application of electricity to driving the rolls in steel mills. The first roll motor was put into service in America in 1906 at Pittsburgh, and the first electrically-driven reversing mill at Chicago soon after.

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[1] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1914, vol. xxx. pp. 778–803.

[2] *Zeitschrift für Dampfkessel und Maschinenbetrieb*, 1914, vol. xxxvii. p. 411.

[3] *Zeitschrift des Vereines deutscher Ingenieure*, 1914, vol. lviii. p. 1429.

[4] *Steel and Iron*, 1915, vol. xlix. pp. 20–21.

[5] Paper read before the Association of Iron and Steel Electrical Engineers; *Iron Trade Review*, 1914, vol. lv. pp. 590–591.

[6] *Iron Trade Review*, 1914, vol. lv. pp. 17–24, 119–125, 131–132.

At present 140 electric rolling-mill engines with an aggregate nominal rating of 176,500 brake horse-power and a maximum rating of 353,000 brake horse-power have been installed at works in America. The latest improvements introduced have consisted of economical regulating devices for the alternating current in induction motors. The introduction in Germany of the Foettinger gear to supersede the herring-bone gear in transmitting the driving power is noted. The chief points discussed as regards electric driving generally are the character of the load; the rating of mill motors and their control; the question of first cost, and that of the heat units required.

H. J. Freyn[1] challenges some of the statements made by Dyckerhoff, and points out the advantages of large gas-engines for driving rolling-mills, and the great improvements that have taken place of recent years in regard to gas-engine practice.

Dyckerhoff[2] replies to the criticisms raised, and points out that local conditions must in all cases be the first consideration of any comparison of the relative merits of electric driving and the use of gas-engines.

Rolling-Mill for Corrugated Tubes.—A new rolling-mill for the production of corrugated flues for boilers is illustrated and described.[3] The plant has recently been installed for the Gelsenkirchener works at Eller, near Düsseldorf, and the mill is capable of rolling corrugated flues of 24 inches up to 78 inches diameter and 23 feet in length. A sectional drawing of the mill is shown, and the reheating furnace for the tubes is also given in detail.

Power Requirements of Rolling-Mills.—G. Meyer[4] discusses the energy consumption of reversible rolling-mills. The report consists of a review of the results obtained by previous investigators in their experiments on the power requirements and friction losses in the driving of rolling-mills.

The application of electric driving in heavy reversing mills for billets and blooms is discussed by W. Sykes,[5] who gives a table of the power requirements of a blooming mill of this type.

F. Denk[6] discusses the power requirements for rolling steel.

Roll-Drafting.—C. Holzweiler[7] has presented a report to the Rolling-Mill Commission of the Society of German Ironmasters, on the subject of improvements in the drafting of rolls for rolling structural iron and steel. The sizes of the draft for channels and Z-beams are given in tabular form.

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[1] *Iron Trade Review*, vol. lv. pp. 340–342, 386–388.

[2] *Ibid.*, pp. 388–389.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1330–1333.

[4] *Ibid.*, 1915, vol. xxxv. pp. 4–13, 38–45.

[5] Paper read before the Association of Iron and Steel Electrical Engineers; *Iron Trade Review*, 1914, vol. lv. pp. 1181–1183 and 1196*c*.

[6] *Steel and Iron*, 1915, vol. xlix. pp. 12–13.

[7] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1405–1408.

Reheating Furnaces.—An illustrated description is given [1] of the Stein reheating furnace. A leading feature in the design is that the gas and air inlet ports are so arranged that combustion takes place in separate chambers, and not over the bed of the furnace. Thus the charge is not exposed to the direct action of the flame, but is heated by radiation from the furnace roof. By means of a special system of recuperating chamber, the incoming air is continuously preheated to a high degree by the outgoing products of combustion. The arrangement of the inlet ports and the means of regulation permit of the employment of a non-oxidising flame, and as a result the surfaces of the material charged are practically free from scale when withdrawn.

A comprehensive review is given,[2] with numerous drawings, of modern types of reheating and annealing furnaces, with particulars of methods of operation and fuel consumption. In a later series of articles, descriptive illustrations of pot-annealing and wire-annealing furnaces are shown.[3]

Amongst others an account is given of the Walther annealing furnace, for the annealing of small billets and blanks previous to final cold-rolling into wire rod and hoop-iron. After the first cold-rolling operation, the material becomes too hard for finishing in the cold rolls, and an annealing operation is necessary before finishing. The formation of scale is, however, very troublesome, and the furnace in question has been specially devised for its prevention. The blanks are fed into one end of an upward inclined retort, through which a stream of non-oxidising gas passes. The upper end of the retort is connected to a cooling tube, through which the blanks continue to travel out of contact with air, until they emerge cool at the further end. Illustrations show the arrangement of the whole furnace. The article concludes with a description of the Vaughan-Hughes muffle furnace.

The application of the electric furnace for reheating, heat-treating, and annealing operations is dealt with by T. F. Baily.[4]

A description is given [5] of the Selas machine for controlling the gas and air supply of heating furnaces. The principle of the machine is to draw in definite predetermined proportions of gas and air, and to mix them together, at the same time distributing this mixture through the service mains under a constant high pressure.

American Rolling-Mills.—An illustrated description [6] is given of the engines and rolling-mills lately installed by the Brier Hill Steel Company, of Youngstown, Ohio. The engine driving the blooming mill is of the twin-tandem non-condensing reversing type. The rolling plant consists of a blooming mill, one continuous mill, and a merchant mill, with all the usual accessory plant.

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[1] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 570.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 609–620, 781–796, 873–879, 1001–1005, 1119–1124, 1595–1604, 1629, 1636, 1687–1691, 1736–1740, 1820–1824.

[3] *Ibid.*, 1915, vol. xxxv. pp. 189–194, 287–292, 421–426.

[4] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1915, vol. xxxi. pp. 255–283.

[5] *Steel and Iron*, 1915, vol. xlix. pp. 161–162.

[6] *Engineer*, 1915, vol. cxix. pp. 229–230.

Details and illustrations of a large new mill put down by the Wisconsin Steel Company at South Chicago have appeared.[1]

C. F. Williams[2] describes the mills of the Franklin Steelworks, Franklin, Pennsylvania, rebuilt after having been totally destroyed by fire in 1913. The mills are designed for the rolling of various commercial shapes from old rails, which are purchased for the purpose, and billets. A special 18-inch mill has been put down to roll U-bars, angles, channels, and other sections, the entire rail being utilised for this purpose.

The large new slabbing-mill at Gary, Indiana, is described.[3] It is to be operated in connection with the 60-inch universal plate mill, which has an output of 10,000 tons per month. The slabbing-mill will take ingots of the largest size up to fifteen tons. There are eight soaking furnaces, each containing four coke-oven gas-fired pits. The gears of the receiving tables of the rolls are all of cut steel, giving a minimum of friction losses and backlash. The large shears will exert a pressure of 3600 tons, and cut hot steel 60 by 20 inches in section.

C. C. Lynde[4] describes the new rolling-mill plant of the Central Steel Company, at Massillon, Ohio. The 34-inch two-high blooming mill is operated electrically. The bar and billet mill consists of two three-high 24-inch mills, and one two-high bull-head.

The new plant and accessories of the American Steel and Wire Company, Birmingham, Alabama, which has a daily capacity of 400 tons, are described[5] and illustrated. The rod mill is of the double Belgian type, working a No. 5 rod from a 4 × 4-inch billet. The rod cleaning and pickling departments and the draw mills are also described.

The development of the rolling-mill is dealt with,[6] and types of mills are briefly described.

Tinplate Mills in America.—The new extensions to the works of N. & G. Taylor Company, at Cumberland, Maryland, are described and illustrated.[7] They comprise a black plate department consisting of three 26 by 30 inch hot mills, and two 26 by 32 inch hot mills. A number of cold mills have been installed, and pickling is carried out by means of a standard three-arm high type Mesta machine. A number of new features have likewise been introduced in the new tin house.

Wire-drawing Machinery.—An illustrated description is given[8] of a wire-drawing bench for dealing with heavy sections of rolled wire rods. It is provided with a variable-speed motor drive in order that the drum can be rotated at the most efficient circumferential speed. The machine is designed for dealing with rods of $\frac{5}{8}$ inch diameter, and reducing them at one draft to $\frac{1}{2}$ inch diameter, the material being mild steel of a breaking strain of 45 tons per square inch.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 127–131.

[2] *Ibid.*, pp. 482–484. [3] *Ibid.*, pp. 679–683 and 696*c*.

[4] *Steel and Iron*, 1915, vol. xlix. pp. 153–157.

[5] *Iron Trade Review*, 1914, vol. lv. pp. 960–963 and 970*c*.

[6] *American Machinist*, 1915, vol. xlii. pp. 287–293.

[7] *Iron Trade Review*, 1914, vol. lv. pp. 75–80.

[8] *Iron and Coal Trades Review*, 1915, vol. xc. p. 122.

The history of wire drawing at Worcester, Massachusetts, is dealt with.[1]

Grinding Machinery.—A new type of grinding machine for finishing surfaces of small tools and other metal objects is described and illustrated.[2] The machine consists of a cast-iron frame provided with a flat table and carrying two wide pulleys, over which runs an emery cloth or other abrasive band. The work is held on the abrasive band, which is supported and kept perfectly flat by the table. An unskilled operator can turn out perfectly accurate work.

G. I. Alden[3] deals with the operation of grinding wheels in machine grinding. He gives an analysis of the action of the wheel when in operation, and shows the distinction between the radial or real depth at which the wheel cuts and the depth which the abrasive grain in the wheel cuts into the material being ground.

Abrasives.—C. Hawke[4] defines the characteristics of abrasives, and discusses the principal features of the preparation of natural and artificial abrasives.

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[1] *American Machinist*, 1915, vol. xlii. pp. 331–334.

[2] *Engineering*, 1914, vol. xcviii. p. 667.

[3] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 16–17.

[4] Paper read before the American Foundrymen's Association, September 1914.

FURTHER TREATMENT OF IRON AND STEEL.

Hardening Furnaces.—An exhibition of the Brayshaw industrial furnaces was held at Sheffield in February 1915, and a short description of these furnaces and their various applications is published.[1]

An illustrated description is given [2] of a salt-bath furnace for heating and tempering high-speed steel articles, designed by S. N. and E. R. Brayshaw.

The requirements that a modern steel-hardening furnace should fulfil in order to meet present-day conditions are enumerated,[3] and particulars are given of the times actually taken for electrically hardening several kinds of tool steels.

Enamelling Furnaces.—Some illustrated descriptions of furnaces for treating enamelled iron and steel articles are published.[4]

Hardening Steel in the Forge.—A comparison of the results of hardening steel in a forge with those obtained by the lead bath method is instituted by A. A. Dowd.[5] The lead bath system often leads to variations in cutting efficiencies when high-speed steel is in question, while forge hardening as carried out by the blacksmith gives more reliable and uniform results. Good results are obtained by slowly heating a tool until the cutting edge is white hot and then carefully quenching in paraffin oil and lard.

Hardening Tool Steel.—J. A. Mathews [6] and H. J. Stagg discuss some of the factors in hardening tool steel, and explain at some length the structural variations of steels as a function of carbon content and temperature, as well as the influence of the critical ranges of temperature on the properties of steel, with particular attention to volume changes. The time of heating is of extreme importance for the strength of the piece: if the heating is too fast, the temperature through the piece is not uniform, while long heating leads to the formation of abnormal size of grain. The metal must be cooled quickly, so as to obtain martensite, which is the correct constituent of steel. The authors illustrate the influence of quenching by two examples which, however, are not tool steels, and describe tests of various quenching media, which included pure water, brine solutions, and various oils. The results obtained are given in the form of curves.

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[1] *Engineering*, 1915, vol. xcix. p. 196.

[2] *Mechanical Engineer*, 1914, vol. xxxiv. p. 428.

[3] *Foundry Trade Journal*, 1914, vol. xvi. p. 654.

[4] *Stahl und Eisen*, 1915, vol. xxxv. pp. 421–426.

[5] *Iron Age*, 1914, vol. xciv. p. 553.

[6] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 141–146.

Tests were also made to determine the relation between hardness after quenching and mass, in the course of which it was found that the smaller the sample, the greater the hardness; and the larger the mass, the smaller the depth of hardness when quenched under similar conditions. It is preferable to draw the temper immediately after hardening. This operation is necessary for two important reasons: (1) The relieving of abnormal strains set up due to quick contraction or expansion; (2) The breaking down of the extremely hard and brittle structure of the quenched steel.

The decrease of hardening on tempering is theoretically explained in the results published by Heyn, while for the effect of time on drawing the temper the authors present data of their own tests, which show that time at the drawing temperature has a marked effect, the general effect of drawing the temper being the more marked, the greater the initial hardness of the piece. The effect of repeated quenching on the shape of steel has been studied by means of a very large number of experiments on crucible steel. Many different results were obtained, as where a steel expanded in length on first hardening, and contracted indefinitely thereafter on repeated hardenings, while another steel expanded in length on two hardenings and contracted on the next two. It was generally found that variable conditions gave variable results, which showed the vital importance of the steel furnished being uniform, both chemically and physically. The authors conclude with a brief discussion of the qualifications of heating furnaces.

J. B. Kommers[1] describes tests that were carried out to determine the heat treatment for plain carbon tool steel that would give the best endurance results under repeated stresses such as are given to the pistons of pneumatic hammers. Three different steels, containing respectively 0·80, 1·06, and 1·30 per cent. of carbon were used in the tests. The results show that the first two gave a higher number of cycles than the third, and in general had a greater ductility. The first steel, however, gave the most uniform results over a fairly wide range of temperatures.

G. W. McKee[2] deals with the heat treatment of high-speed steel, and discusses the influence of the various constituents, forging and hardening.

H. M. Howe[3] discusses the hardening of various alloy steels, with and without martensisation.

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[1] *American Machinist*, 1915, vol. xlii. pp. 551–553.

[2] *Page's Engineering Weekly*, 1914, vol. xxv. pp. 434–437.

[3] *Transactions of the Faraday Society*, 1915, vol. x. pp. 265–270; *Engineering*, 1915, vol. xcix. pp. 87–89.

Influence of Heat Treatment on Structure of Steel.—By slowly cooling an overheated steel, having a carbon content of 0·28 per cent., C. H. Desch[1] has obtained a martensitic structure without increase of hardness. Examination with an immersion objective showed the whole mass to consist of pearlite, packed closely in some parts and loosely in others. The author rejects the view held by Edwards and Carpenter that martensite and austenite are constitutionally identical, the former being repeatedly twinned, and that its hardness is due to the formation of amorphous material at the surfaces of the slip on which twinning occurs. It is considered that the martensitic structure is an accompaniment and not the cause of the hardness of a quenched steel, martensite being so much harder than its components as to suggest the presence of a solid solution.

W. P. Ishewsky[2] has studied the production of granular pearlite in steel which contained carbon 0·83 per cent., manganese 0·38 per cent., and sulphur 0·03 per cent., and was heated in an electric vacuum furnace to 800° C., and then cooled to 680° C. This was repeated eleven times, at intervals of 20 minutes. During cooling the transition temperature, which had a slight tendency to rise, was 704° C. to 712° C. After treatment the structure was coarser, the granular pearlite had increased, the lamellar was less in amount, but composed of larger particles, the cementite had increased, and free ferrite was present. It was shown by treating a second sample containing carbon 0·37 per cent., silicon 0·38 per cent., manganese 0·98 per cent., phosphorus 0·05 per cent., and sulphur 0·03 per cent., that this result was not due to the original presence of cementite. The mechanical properties were :—

Sample.	Tensile Strength.	Elongation.
	Tons per Sq. In.	Per Cent.
(1) 0·83 per cent. carbon before treatment . .	48·7	11·8
(1) 0·83 per cent. carbon after treatment . .	34·2	19·75
(2) 0·37 per cent. carbon after treatment . .	31·2	21·25

J. Lund[3] deals with the heat treatment of low-carbon steel, and shows by means of photomicrographs the internal structure of a piece of steel from the cast ingot, and also after forging and subjecting it to various heat treatments. The physical properties of each specimen are also given.

E. A. Suverkrop[4] deals with the heat treatment of railway axles and rods.

In pointing out that the strength of low-carbon steel can be greatly increased by subjecting it to a suitable heat treatment, C. J. Atkinson[5] describes some tests carried out on the web of a large crank-shaft.

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[1] *Transactions of the Faraday Society*, 1915, vol. x. pp. 255–256.

[2] *International Journal of Metallography*, 1914, vol. vi. pp. 199–200.

[3] *American Machinist*, 1915, vol. xlii. pp. 505–506.

[4] *Ibid.*, pp. 353–356. [5] *Ibid.*, pp. 639–640.

J. H. Herron[1] deals with the properties, treatment, and selection of iron and steel for engineering purposes.

R. R. Abbott[2] discusses the theory of heat treatment of steels.

Heat Treatment of Nickel Steels.—H. Meyer[3] has carried out an investigation with the object of determining more exactly the range of temperatures for the heat treatment of pearlitic nickel steels. Almost all existing data are based upon the observations of cooling curves which, the author considers, give unsatisfactory conclusions, since any appreciable change in the proportion of nickel and other elements affects the critical points. Micrographic analysis is recommended as a more trustworthy method of calculating the temperature for heat treatment of nickel steels, and the data obtained by this method are tabulated for various nickel steel alloys, numerous micrographs of which are shown. The influence of nickel and manganese on the temperature of the A3 transformation point of iron-carbon alloys is also shown in tabular form. A series of tests of the material, combined with a micrographic investigation, illustrates the value of the author's results.

Heat Treatment of Gears.—W. H. Phillips[4] describes the manufacture of railway gearing, and refers to a new method of heat treatment called the B. P. process. This consists of the following sequence of operations: annealing, machining, quenching and drawing. A careful selection of the raw material and the quenching operation constitute the main features of the high quality of the product. The B. P. process produces a very hard material with a high tensile strength, and retention of ductility. The hardness diminishes gradually from the wearing surface to the centre of the tooth.

In the discussion which followed the reading of this paper, W. R. Wigley[5] refers to a series of tests on the resistance of steel to fatigue and the effect of heat treatment upon that resistance. Four grades of steel were used in the tests, the carbon content of the test-pieces being 0·14, 0·32, 0·60 and 1·02 per cent. The pieces were tested by bending them backwards and forwards, thus setting up transverse stresses in the material. For each piece the bending stress was computed, and the number of cycles of bending counted. By changing the motion of bending in the various pieces of a series, it was possible to determine the life of the material at various stresses. From the curves shown, it is evident that at any stress the higher carbon steels withstood the repeated stresses better than the lower carbon steel. In these tests, however, the loads were applied without impact, and impact might change the relation to some extent. The tests seem to indicate that there is no such thing as a natural elastic limit at stresses below which a steel will have infinite life against repetitions of load.

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[1] Paper read before the Cleveland (U.S.A.) Engineering Society; *Mechanical Engineer*, 1915, vol. xxxv. pp. 10–13.

[2] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 267–271.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1395–1405, 1456–1461.

[4] *Proceedings of the Engineers' Society of Western Pennsylvania*, 1914, vol. xxx. pp. 737–777.

[5] *Ibid.*, pp. 767–769.

J. H. Parker[1] states that the proper heat treatment for case-hardened gears is the so-called double treatment, by which the pieces are first allowed to cool in the box after carbonising, and are then reheated to 1550° or 1625° F., and quenched in a suitable medium to refine the core. They are then reheated to 1350° to 1425°, and again quenched in a suitable medium to harden the case. Finally they are drawn in oil at not above 400° to increase further the strength and toughness of the case-hardened gear. The equipment required for carrying out heat treatment is described.

Annealing Malleable Castings.—O. W. Storey[2] gives the results of experiments carried out on the annealing of malleable castings. The annual production of such castings in the United States is over a million tons, but although the industry is so important, scientific progress has been slow, and each plant works under different conditions. The experiments carried out bore on the effect of the following factors upon the annealing process: (1) Packing materials. (2) Temperature of annealing. (3) Time of annealing. (4) Rate of cooling. The experiments showed that the physical and chemical constitution of the packing materials influence the skin structure of the annealed casting, but have no apparent effect upon the interior in the American "black heart" practice. Loose packing which allows the free circulation of oxidising gases will result in a carbonless rim, whereas a slightly oxidising atmosphere will result in a steely rim. Experiments on the effect of temperature showed that with an annealing time of fifty hours white iron required a temperature of 860° to secure a complete breakdown of the cementite. At lower temperatures the breakdown was partial only, and below 670° no decomposition would be observed. The effect of the rate of cooling from the annealing temperature showed that the fast rate of cooling results in a steely structure, and that the critical cooling range is between 740° and 830°. Very slow cooling will result in a ferrite rim. The general conclusions embodied go to show that the decomposition of the iron-carbide is complete above the Ar1 point of the iron-carbon diagram. Whether iron-carbide is unstable below the Ar1 point has not been determined. The decomposition of the iron-carbide is not complete at the annealing temperature, but is complete in a range of temperature just above the Ar1 point.

Influence of Annealing on Steel Castings.—P. Oberhoffer[3] discusses the influence of annealing on the physical and mechanical properties of steel castings. Material containing different percentages of carbon and manganese was experimented with, and the results in general show that annealing at temperatures from 770° to 1000° increases the tensile strength, elongation and limit of elasticity. In low carbon steels the specific work producing fracture by impact is increased by annealing (in the steel with carbon = 0·26 it rose from 2·94 to 7·42 metre-kilogrammes per square centimetre, after annealing six hours at 1000° C.), but in steels containing over 0·5 per cent. of carbon annealing had little effect on the resistance to impact.

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[1] Paper read before the National Machine Tool Builders' Association, U.S.A.; *Mechanical Engineer*, 1915, vol. xxxv. p. 357–359.

[2] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 383–389.

[3] *Stahl und Eisen*, 1915, vol. xxxv. pp. 93–102, 212–216.

Drop Forging.—A. Stubbs[1] deals with the manufacture of drop forgings, and describes the class of carbon steels and alloy steels used in the manufacture of automobile parts. Nickel-chromium steels are used very extensively, and may be divided into two classes, those containing low chromium and nickel content, and those containing high chromium and nickel content, the latter being used almost exclusively for gears which are required to have a very great hardness. The author also shows the physical properties of nickel, nickel-chromium, and chromium-vanadium steels before and after heat treatment.

Forged Locomotive Pistons.—W. W. Scott, Jun.,[2] discusses the use of forged and rolled steel pistons in modern locomotives, chiefly as a means of reducing the weight of reciprocating parts, and thereby decreasing the dynamic disturbances at the rails. He also describes a new method of manufacturing pistons developed at the Homestead Works of the Carnegie Steel Company. The ingots are cast into moulds 22 × 22 inches and about 6 to 7 feet long. After being rolled into blooms 15 inches in diameter, they are sheared, while hot, into "cheeses" of the proper weight to produce the required section. This shearing of the blocks from rolled rounds into the form of discs is due to the fact that the outside of the ingot finally becomes by this process the outside or periphery of the section, while the centre, naturally the weakest part, finally becomes the core, and goes back into scrap.

Influence of Finishing Temperatures on Physical Properties of Rails.—W. R. Shimer[3] gives the result of a number of experiments on the rolling of rails from reheated blooms, at a temperature somewhat higher than those used when the rails are rolled direct from the ingot. The object of the experiments was to determine the best finishing temperature for steel rails. The results were inconclusive, but it was shown that rails rolled from reheated blooms are more ductile than those rolled direct from the ingot. Caution is needed in regard to judging from the microstructure the temperature at which a rail had been finished, or in drawing conclusions from the microstructure in cases of rail failure. Microstructure appears to be controlled more by the rate of cooling from above the critical point than by the temperature at which it was finished. In regular practice rails cool uniformly, since hot rails are going to the bed continually, and the microstructures do not vary much. A number of photomicrographs illustrative of the structure of the various steels employed, and tables showing the tensile strength and drop tests, are given.

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[1] Paper read before the Institution of Automobile Engineers, May 12, 1915; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 722–723.

[2] *Proceedings of the Railway Club of Pittsburgh*, 1914, vol. xiv. No. 1.

[3] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 557–585.

Removal of Seams in Steel Rails.—R. W. Hunt[1] deals with the mechanical elimination of seams in steel rails. He points out that increased weight of rolling stock and speed of traffic have led to increase in sizes of rail sections, requiring changes in the detail of rail manufacture. One of the chief troubles developed in the heavier rails has been failures through crescent-shaped pieces breaking out of the rail flanges. Investigation shows that in practically every instance of such failure there was a more or less pronounced seam running longitudinally in the bottom of the rail near its centre. As a result of an investigation, T. H. Mathias came to the conclusion that the most sure way of getting rid of seams was to remove that portion of the metal which contained them. It was demonstrated also that the surfaces of the ingot are decarburised to the extent of 8 to 10 points carbon, and to a depth of $\frac{5}{16}$-inch, which must be detrimental to the finished product.

The removal of the surface metal is effected by a hot sawing, or milling operation during the process of rolling. The ingot is first reduced to a point where the product is 75 per cent. finished, in the form of a partially shaped bar, 60 feet long, when it is entered between two pinch rolls with the flange side up, and forced between two milling saws. A second set of rolls pulls the bar and aids in holding it in line for the milling operation, for which purpose milling saws 5 feet in diameter are used. Metal is removed from the top and bottom of the bar, the main object being to eliminate the seams from the central portion of the bottom of the rail, which has been the starting point of the failures, and to remove them from the top or bearing surface of the head of the rail.

Manufacture of Tubes.—J. G. Stewart[2] describes the process of manufacture of wrought iron and steel tubes. In present-day methods of manufacture at least 95 per cent. are welded or weldless, the remainder being made by the lock bar and riveted processes, both of which are limited to the larger sizes of pipes.

W. Trinks[3] deals with the deformation of metals during rolling.

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[1] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 152–156.

[2] Paper read before the Institution of Engineers and Shipbuilders in Scotland; *Iron and Coal Trades Review*, 1915, vol. xc. pp. 608–610.

[3] *Steel and Iron*, 1915, vol. xlix. pp. 276–277, 422–423.

Hollow Steel Rolls.—J. C. H. Ferguson[1] deals with the manufacture of rolled steel roll shells for grinding appliances. Tables are given showing the physical and chemical requirements to which the material should conform. The extreme limits for the chief constituents are shown below:—

	Per Cent.
Carbon	0·65 to 0·80
Phosphorus, not above	0·05
Sulphur, ,, ,,	0·04
Manganese	0·60 to 0·85
Silicon	0·15 to 0·3

Special attention is also necessary to the resistance of the metal to abrasive wear. The cylindrical ingots used are obtained by pouring the molten metal into cast-iron moulds and discarding the top or segregated portions. They are then heated, forged, and rolled to the required dimensions. The rolling is carried out in a tyre mill, the faces of the shell being simultaneously subjected to very high hydraulic roll pressure. Examples are given, taken from actual mill practice, showing the average life of well-made rolls of this description.

Manufacture of Guns and War Munitions.—A. Schwinning[2] gives a long account of the construction of modern small arms, field guns, fortress guns, mines and torpedoes, and the material used in their manufacture.

A description has appeared[3] of the method of manufacturing of cartridge cases for 6-inch rapid-fire guns.

Manufacture of Shells.—Articles describing the manufacture of shrapnel shells have appeared.[4]

Sheet-Rolling Practice.—H. Beard[5] reviews the developments made in the manufacture of sheets and plates. Sheet rolling commenced in this country in 1728. Coxe, in his "Historical Tour in Monmouthshire," published in 1801, refers to John Hanbury, who, in the early part of the eighteenth century, invented a method of rolling iron plates by means of cylinders, and introduced the art of turning into England. With regard to the conditions prevailing thirty years ago, all mills in Scotland were steam-driven; they were frequently unequal to the demands made upon them, and breakdowns were regular occurrences. The mills were light, having housings of cast iron weighing about seven tons, rolls 21 inches to 24 inches in diameter, necks and wobblers disproportionately small. The furnaces were coal-fired, and the shearing machinery was principally of the crocodile type, and the length of cut was very short. Accordingly the process was slow and laborious, and 3½ tons of lattens were reckoned an average shift of twenty-four hours, the scrap loss in pile rolling being about 33⅓ per cent. In present-day practice, rolling from the sheet-bar, an output of seven tons of lattens can be obtained in twelve hours, with a scrap loss of 12 to 15 per cent. Up to the present time all attempts to introduce mechanical appliances in the heating and rolling operations essential to the production of thin sheets have failed.

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2333–2344.

[2] *Zeitschrift des Vereines deutscher Ingenieure*, 1914, vol. lviii. pp. 1653–1662, 1683–1694.

[3] *American Machinist*, 1915, vol. xlii. pp. 177–181.

[4] *Ibid.*, pp. 89, 91, 321, 397, 439, 449, 473, 493, 537, 607.

[5] *Journal of the West of Scotland Iron and Steel Institute*, 1914–15, vol. xxii. pp. 21–26.

The author gives the following typical analysis of steel sheet bars, with notes regarding behaviour during rolling:—

A.	Per Cent.	
Carbon	0·125	Did not roll well; showing a tendency to stick.
Silicon	traces	
Sulphur	0·071	
Phosphorus	0·089	
Manganese	0·462	

B.		
Carbon	0·105	Rolled very badly, stickers and blisters occurring regularly.
Silicon	0·036	
Sulphur	0·058	
Phosphorus	0·087	
Manganese	0·410	

C.		
Carbon	0·100	Gave excellent results in rolling latten.
Silicon	nil	
Sulphur	0·048	
Phosphorus	0·037	
Manganese	0·487	

Rolling Bright Steel Bars.—An illustrated description[1] is given of the plant of the Coghlan Steel and Iron Company, Limited, Hunslet, Leeds, for the production of bright steel bars by the Josserand and Jacquet process. The bars are produced by turning, and not by the usual drawing process, and are rolled to within $\frac{1}{100}$-inch and $\frac{1}{20}$-inch of the finished size. The special machines for finishing the bars consist of six heads placed in a tandem on a common bed-plate, but driven independently from the line shafting, the work performed in the various passes being (1) straightening, (2) pulling through, (3) roughing cut, (4) pulling through, (5) finishing cut, and (6) planishing.

Tinplate Rolling Practice.—J. Williams[2] discusses methods of improving Welsh tinplate rolling-mill practice, and points out the progress made in the United States. He suggests a scheme of rolling which might be made the nucleus of a new practice. In this scheme the mill should consist of four stands of rolls placed in line, and situated 12 feet apart; three furnaces 14 feet long, 4 feet high, and 4 feet wide; and two small furnaces for heating the iron, similar to those used in sheet mills. The iron would be rolled in the first pair of rolls, matched in the second, the fours rolled in the third, and the eighths in the fourth rolls. Upon the pair of iron being finished, it is thrown down by the roller in the usual way, then, instead of being lifted into the furnace, it is merely slid within the reach of a mechanical arm, which carries it into the furnace. On entering the furnace the plate travels to the prescribed limit, and is ejected perfectly heated for rolling again. After passing through the second pair of rolls, the plates are opened and doubled in the ordinary way, and then thrown by the doubles into the reach of an arm, which slides them into a second furnace. They then pass to the rollerman in the third pair of rolls, and so on to the fourth rolls, where they are finished. The author also suggests the adoption of a reversing gear at tinplate mills.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. pp. 114–115.

[2] *Proceedings of the South Wales Institution of Engineers*, 1915, vol. xxxi. pp. 151–170.

S. R. Cound[1] also discusses the same subject.

W. Krämer[2] gives an account of the present position of the tinplate industry. At present there are not more than seven works where tinplate is manufactured, and these are all situated in West Germany. Illustrations show some of the tinning and cleaning machines in use, and a section through a tinning shop.

A White Paper has recently been issued by the Home Office giving the report by J. H. Rogers on the question of health and safety in tinplate works.

Wire-drawing.—B. Rydberg[3] takes up the question of the cup and cone phenomenon in wire-drawing. His chief contention is that the usual form of relieving the ingoing side of the die is incorrect,[4] and that instead of a simple cone up to the draw-hole it should have, for some distance before reaching the actual gauge hole, a cone of longer height with an easy run where the two cones meet. The author gives a sketch illustrating his views. O. Tingberg appends a paragraph setting out his view that molecular action is partly the cause, but emphasizes the opinion that it is mostly due to an attempt to reduce the diameter of the wire too much at one draw.

Welding.—P. Schimpke[5] gives a description of modern methods of welding, with illustrations of apparatus and the mode of their application.

For protecting the head and eyes of the operatives during electric and autogenous welding and cutting, an inexpensive aluminium helmet, weighing only 28 ounces, is described[6] and illustrated.

J. F. Lincoln[7] considers the fundamental principles of arc welding of metals in relation to the following points: (1) the metals that can be melted by the electric arc; (2) the difficulties encountered in electric arc welding; (3) the strength of the weld in comparison with the original piece; (4) the cost of welding; and (5) the function of the arc welding machine.

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[1] *Proceedings of the South Wales Institute of Engineers*, 1915, vol. xxxi. pp. 172–210.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1785–1791.

[3] *Bihang till Jernkontorets Annaler*, 1914, pp. 39–47.

[4] *Engineering*, 1907, vol. lxxxiv. p. 191.

[5] *Stahl und Eisen*, 1915, vol. xxxv. pp. 385–392 *et seq.*

[6] *Iron Trade Review*, 1914, vol. lv. pp. 294, 303.

[7] Paper read before the American Institute of Electrical Engineers, March 18, 1915; *Mechanical Engineer*, 1915, vol. xxxv. p. 321.

Oxy-Acetylene Welding.—Modern progress in the application of oxy-acetylene welding is exemplified by a description[1] of some large repairs done by the Anaconda Company in repairing its main dust flue, a task which involved over 10 miles of welding. The Davis-Bournonville apparatus was employed, with 24 electrolytic oxygen-generating cells, one purifier, one pressure regulator, 2 gasometers with regulators, one 2-stage compressor, one 300-lb. per sq. in. compressor, and one 3-stage 2000 lb. compressor, 27 tanks for oxygen at 2000 lbs. pressure. When using the welding apparatus the oxygen consumption at Anaconda was about 1000 cubic feet per day. The work was commenced in October 1913 and completed about 12 months later, during which time 53,365 linear feet of welding was done with 350,000 cubic feet of oxygen and about 40,000 lbs. of calcium carbide. Other applications of acetylene welding for the repair of broken mining machinery at Anaconda and elsewhere are described. The strength of oxy-acetylene welds is variously estimated at 50 per cent., and at the same as the original parts, but much depends on the skill and care of the operator. The application of the heat and the complete fusing of the metal without burning require a high degree of skill, and the success of the weld is almost wholly in the hands of the operator.

The welding of malleable cast iron by means of the oxy-acetylene process presents various difficulties, inasmuch as the fusion of a finished casting reduces the malleable iron to practically its original white hard condition.[2] From experiments carried out in the United States by the Superior Oxygen Company, it has been found that satisfactory results can be obtained if, after the casting has been annealed and taken from the furnace, the crack or hole that requires repairing is chamfered out as usual and the blowpipe flame applied until the casting becomes fused at the point to be welded. A suitable malleable-iron filling rod is then fused into the defect with the aid of a special flux, until the defect is entirely closed and a smooth homogeneous weld results. The weld, which at this stage is very hard and brittle, is rendered soft and malleable by putting the casting again through the entire annealing process.

A. L. Smith[3] discusses the efficiency of the oxy-acetylene weld from the results of tests of 60 welds made by this process.

G. H. Manlove[4] describes the acetylene welding of pipe joints.

Electro-percussive Welding.—C. E. Skinner[5] and L. W. Chubb describe electro-percussive welding, which consists in causing a condenser discharge to pass between the ends of the metals to be welded at the moment when they are pressed together by mechanical force. By this process steel can be welded without undergoing any detrimental local softening, even when tempered spring qualities are employed.

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[1] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 393–397.

[2] *Foundry Trade Journal*, 1914, vol. xvi. p. 644.

[3] *American Machinist*, 1915, vol. xlii. pp. 591–593.

[4] *Mining and Engineering World*, 1915, vol. xlii. p. 553.

[5] Paper read before the American Electro-chemical Society; *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 713–714.

Enamelling Iron and Steel.—E. Skamel[1] gives some notes on the practice of enamelling cast iron. The manufacture of the enamel is also described.

The new works of the General Stamping Company, Canton, Ohio,[2] for the manufacture of enamelled steel goods are illustrated and described. The capacity of the works is 100,000 pieces daily.

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[1] *Giesserei Zeitung*, 1914, vol. xi. pp. 606–609.

[2] *Iron Age*, 1914, vol. xciv. pp. 10–13.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties of Cast Iron.—J. E. Stead[1] deals with some scientific features of cast iron. Contrary to the conclusions of some chemists, all cast iron, no matter how grey during its passage from the commencement of solidity to the cold condition, invariably commenced white and then gradually changed to grey during cooling. The greyness was the result of decomposition of a definite chemical compound, carbide of iron, which had a white fracture. An explanation is given as to why some very high-class and valuable pig irons have a white centre and an open grey envelope.

J. E. Hurst,[2] in dealing with the causes of variations in mechanical properties of cast irons of identical compositions, gives the results of tests carried out on a number of irons.

F. J. Cook[3] discusses the nature and properties of cast iron.

C. Heggie[4] discusses the cooling of cast iron in relation to strains and warps in light castings.

Influence of Vanadium on Pig Iron.—E. O. Fitch, Jun.,[5] discusses a series of tests made on samples of commercial pig iron containing vanadium, for the purpose of ascertaining its influence. The vanadium was in all cases below 0·05 per cent. Closeness of grain and softness under the tool are the characteristics of all iron containing vanadium. Such irons also take a fine polish.

Influence of Various Elements on Cast Iron.—F. Wüst[6] and R. Stotz have investigated the influence of phosphorus on grey cast iron. Cast-iron test-bars with varying percentages of phosphorus were prepared, and a table giving the results of the mechanical tests is appended to the report. The transverse test gave a mean breaking strength from 39·60 kilogrammes per square millimetre with 0·16 per cent. of phosphorus, down to 25·80 with 2·04 per cent. of phosphorus.

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[1] Lecture delivered before the British Foundrymen's Association, January 23, 1915; *Foundry Trade Journal*, 1915, vol. xvii. pp. 144–147.

[2] *Foundry Trade Journal*, 1915, vol. xvii. pp. 82–83.

[3] Lecture delivered before the British Foundrymen's Association, November 28, 1914.

[4] Address delivered before the British Foundrymen's Association, October 24, 1914; *Foundry Trade Journal*, 1915, vol. xvii. pp. 31–37.

[5] *Iron Trade Review*, 1914, vol. lv. pp. 72–74.

[6] *Ferrum*, 1914–15, vol. xii. pp. 89–96.

The hardness at the same time increased regularly from 234 (Brinell) to 327.

J. E. Johnson, Jun.,[1] deals with recent developments in the manufacture of cast iron, and discusses the effect of various elements on the properties of cast iron.

Tests of Cast Iron.—O. Leyde[2] reviews the progress made in the methods of testing cast iron and in the development of standard test-bars for securing uniformity of results.

Specifications of Cast Iron.—The standard specifications of the American Society for Testing Materials for cast-iron car wheels are given.[3]

G. Strelin[4] recommends the raising of the requirements of the German standard specifications of cast iron. The results of various tests are recorded, showing that with a good quality of metal the standard breaking stress and deflection of a 30-millimetre round bar 600 millimetres long might be increased from 34 to 38 kilogrammes per square millimetre in the case of high quality machine castings.

Influence of Natural Chill on Malleable Castings.—G. M. Thrasher,[5] in dealing with the subject of iron mixtures, discusses the significance of natural chill of cast iron in relation to the manufacture of malleable castings. Mere regulation of silicon is insufficient to produce the desired degree of chill, and variations in total carbon have a strong influence. A chart is given showing lines of equal natural chill in terms of silicon and carbon percentages, and their application in making malleable castings. The lines have been confirmed by plotting many analyses of mixtures of known chill and normal pouring temperature.

Strength of Malleable Cast Iron.—E. Touceda[6] gives some interesting data regarding the strength of malleable cast iron.

Detection of Blowholes in Steel by means of Radiographs.—W. P. Davey[7] deals with an interesting application of the X-ray for the purpose of detecting blowholes in steel castings. He describes the method of examination of a steel casting, the homogeneity of which was suspected, and gives a radiograph showing the flaw in the centre of the casting. All the radiographs showed plainly the tool marks on the surface of the casting, and all but one showed peculiar markings, which were of such shape as to suggest that they were indeed pictures of holes in the interior. In order to confirm this a circular piece 1 inch in diameter and $\frac{9}{16}$-inch in thickness was punched from the casting at a point where one of the radiographs indicated that a blowhole should be found. The surface of the casting at the point where the punching was made was entirely free from blowholes, but from photographs of the edge of the button the expected hole is plainly seen.

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[1] *Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 59–93, 171–213.

[2] *Giesserei Zeitung*, 1914, vol. xi. pp. 569–571.

[3] *Year-Book of the American Society for Testing Materials*, 1914, pp. 242–247.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1649–1652.

[5] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. pp. 39–40.

[6] *Foundry*, 1915, vol. xliii. pp. 13–15.

[7] *General Electric Review*, 1915, vol. xviii. pp. 25–27; *Mechanical Engineer*, 1915, vol. xxxv. p. 97.

Hardness Tests.—E. J. Kelly[1] compares the various methods of ascertaining hardness, and shows the relative indications obtained by various methods, including the scleroscope and Brinell tests. The specific application of the different kinds of test to ascertain different kinds of hardness is described.

A. Portevin[2] has examined the shape of the impression formed by the dropping ball in the ball test in the case of various alloys possessing a coarse-grain structure. Examples were taken where only one grain had been struck under various conditions, and where several grains, similarly orientated, had been struck. The results show that the impression on each grain is far from being circular on account of the mechanical anisotropy of the grain. An explanation is thus afforded as to why the impressions obtained in the case of metals and alloys with large grains, oriented in such a manner that several grains are deformed, are extremely irregular and do not give any exact measurements.

Relation between Tensile Strength and Hardness.—W. K. Shepard[3] and C. T. Porter give details of an investigation undertaken in order to determine the relation between the ultimate tensile strength of cold-rolled steel and the hardness number as found by the Brinell and scleroscope tests. Consideration of the results leads the authors to believe that the Brinell hardness test gives valuable indications of the ultimate strength, while the scleroscope test is not of great value in determining this property.

Hardening and Overstrain in Metals.—G. T. Beilby[4] states that the causes of hardening of metals and alloys are classed under two heads: I. Hardening of a pure metal might be caused by cold-working or by chilling. II. Hardening of alloys, of mixtures of metals, or of mixtures of metals and metalloids, might be caused by cold-working, by chilling, or by the mere admixture of different kinds of molecules, either simple or compound. In Class I., if the amorphous-crystalline theory of hard and soft states was accepted, no further explanation was needed, but in view of the fact that this explanation was not yet universally accepted, the facts and conclusions on which the theory was based are briefly discussed. If the amorphous-crystalline theory was accepted for Class I., it must also be accepted for Class II., wherever the condition of flow at internal surfaces could be shown to exist either as a result of cold-working or from contraction strains due to chilling. In this class the amorphous or thermally-metastable state might also be produced by sudden solidification from the liquid state. Even when solidification was complete during subsequent slow-cooling, molecular arrangement among the different constituents or phases might occur, and these changes might make either for greater or less hardness of the aggregate in whole or in part.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 117–118.

[2] *Comptes Rendus*, 1915, vol. clx. pp. 344–346.

[3] *American Machinist*, 1915, vol. xlii. pp. 277–278.

[4] *Transactions of the Faraday Society*, 1915, vol. x. pp. 212–215.

Interstrain Theory of Hardness.—A. McCance[1] discusses the interstrain condition of iron in which the arrangement of the atoms in the original crystalline structure is so far disturbed that the atoms can no longer return to their positions of equilibrium, and states that it is this condition which is considered to involve increased hardness.

Influence of Cold-Working.—H. Wald[2] gives the results of an investigation of the influence of cold-working upon the tensile strength and other mechanical properties of steel.

Brittleness due to Working at Blue Heat.—E. Preuss[3] has investigated the brittleness in mild steel arising from working at a blue heat. A number of test-bars were prepared, on two of which the number of blows necessary to produce rupture in the normal state was determined, a Krupp duration-impact testing machine being used for the purpose. The remaining bars were heated in an oil-bath, and of these, three were stretched at 250° C. and three at 300°. They were first all loaded to the elastic limit, and the three bars of each series were then stretched while hot to an elongation of 1·7, 4·2, and 8·3 per cent. and subjected to the duration-impact test. The brittleness was found to have increased to a notable degree, and more particularly in the case of the bars stretched at a temperature of 300° rather than in those at 250°. The bars which were stretched 8·3 per cent. at 300° gave an impact number, 173 times, 30 times, and 688 times less respectively than the number given by the same material in the normal condition. The full results are shown in diagrams and tables, and a good illustration of the Krupp testing apparatus is given.

G. Charpy[4] states that the brittleness of steel increases regularly with the temperature of deformation, and attains a maximum, varying according to the nature of the steel, at about 250° C., this temperature being coincident with that of minimum ductility, and nearly 200° below that of minimum resilience.

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[1] *Transactions of the Faraday Society*, 1915, vol. x. pp. 257–264.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1705–1710.

[3] *Ibid.*, pp. 1370–1374.

[4] *Comptes Rendus*, 1914, vol. clviii. pp. 311–314.

Brittleness and "Bursting."—C. de Fréminville[1] deals exhaustively with the phenomena of brittleness exhibited by metals. Investigations on the subject were carried out to ascertain the causes of fractures which occurred suddenly and occurred in brittle metals with the features to be identified with the idea of bursting. The latter phenomena is not well understood, and the term is loosely applied, meaning splintering, fragmentation, sudden fracture unaccompanied by deformation, explosion, and even detonation, according to the circumstances in which it occurs. The definition adopted in the present research is as follows:—

"Bursting is a sudden and violent mode of fracture, resulting in numerous fragments, and when completely produced shivering the bodies in which it occurs to fragments." The various forms which bursting assumes are classified into types, and their consideration leads to the enunciation of the following law: All fractures have as their starting point a bursting which arises within the mass and is propagated by succession. In sudden fracture the bursting effect is distributed; in gradual fracture it is localised. The initial bursting takes place in an area where the predominant stress is positive, but not necessarily at the point where that strength attains its maximum. Other things equal, the stress perpendicular to the predominant stress is the determinant of danger or fracture.

This view of bursting has important applications in practice, particularly as the bursting moment, so to speak, is the sole factor in occasioning fracture. How to produce it when required and to prevent it when desired constitute an important aspect of working metals, and indeed other bodies. It was known to primitive man, who applied it to the chipping of his flint weapons, and it is equally applicable when using modern high-speed tools in the machine shop. A number of illustrations of fracture by bursting are given, and it is shown that the fractures occurring in steel resemble and are due to the same cause as those in glass, asphalt, etc., the physics of fracture being substantially similar in all cases. The illustrations, showing as they do the lines along which crepitation occurs, indicate the directions in which tools should be used, and the best modes of lubricating them to mimimise shock and increase useful effect. The explosive rupture or bursting of bodies under tension is further illustrated by diagrams and photographs. Variants of the general laws of bursting, adaptable to special circumstances, are also given, to serve as guides in practical working.

Influence of Machining on Tensile Tests of Bars.—E. P. Withrow[2] and L. C. Niedner find that the effect of turning specimens of reinforcing bars is to raise the yield point and ultimate strength by an amount which may reach 10 per cent. This is true of constant-section deformed bars, and even of plain bars. The increase is not due to protection from the grips by the large ends of turned specimens, for if the specimens are turned to the same diameter for their full length, the increase still exists. The indications are that it is caused by the chemical and structural non-uniformity of the bars. Since the removal of the exterior steel tends to give a higher value for the bars than would be developed in service, the machining of test specimens of reinforcing bars should not be allowed.

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[1] *Revue de Métallurgie, Mémoires*, 1914, vol. xi. pp. 971–1056.

[2] *Proceedings of the American Society for Testing Materials*, 1914, vol. xiv. Part II. pp. 90–106.

Elastic Strength of Metals.—F. C. Thompson[1] describes his investigation of the elastic strength of metals.

F. C. A. H. Lantsberry[2] deals with the changes which the internal structures of metals undergo when sufficient stress is applied to them to put them in a state of strain.

Deformation Lines in Manganese Steel.—H. M. Howe[3] and A. G. Levy have investigated the question as to whether the deformation lines in manganese steel are twins or slip bands, and have decided in favour of the latter interpretation. The evidence in favour of the view that the lines are not twins but slip bands is that they begin and develop like slip bands in other metals; that they bear to the twins in manganese steel the same relation as regards order of magnitude that the slip bands bear to the twins in other metals; the conditions under which they form are those under which slip bands form in other metals, but unlike those under which twins form; that in other metals deformation always causes slip bands but may or may not cause twins, and hence the fact that these lines always form when manganese steel is plastically deformed, whereas the typical twins only rarely do so, suggests by analogy that they are slip bands. Finally, the amorphisation that accompanies their formation would naturally accompany the formation of slip bands but not that of twins. A number of photomicrographs illustrate the points under consideration.

Stresses in Rivets.—H. Kayser[4] has carried out experiments which confirm the work of previous investigators and the results of calculations in that they show that the initial stresses in rivets and screws exercise no injurious effect so long as they are below the elastic limit of the material. Under those conditions the material does not elongate under a load which does not exceed the initial rivet stress.

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[1] Paper read before the Faraday Society, May 11, 1915.

[2] Paper read before the Manchester Association of Engineers, January 9, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 38–41, 62–65.

[3] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 587–600.

[4] *Zeitschrift des Vereines deutscher Ingenieure*, 1914, vol. lviii. pp. 1402–1405.

Tests on Rivets.—Some tests on rivets and riveting material are described by Y. Taji.[1] Mild steel of Japanese manufacture was used and high-tensile steel of British make was also tested. The shearing strength of the finished rivets proved to be almost invariably greater than that of the raw material even when the former had been somewhat overheated. The influence of various methods of riveting is investigated, and since it is difficult to secure a finishing temperature of 750° C. for rivets closed by hand or by pneumatic riveters, it is suggested that hydraulic machines should always be used for high-tensile steel rivets. Comparative tests of high-tensile mild steel rivets show that the former material withstands sudden shock better than the mild material. In general, the experiments show the superiority of the hydraulically-closed rivets.

Electric Resistance of Iron at Varying Temperatures.—G. K. Burgess[2] and I. N. Kellberg have examined the variation of the resistance of pure iron at temperatures between 0° and 950°. The results show that the resistance of iron increases at a gradually increasing rate until the neighbourhood of the first critical region (A2) is reached. This region is characterised by a point of inflexion on the resistance temperature curve at 757°. With a further increase of temperature an abrupt fall in the resistance occurs at about 894°, and the reverse change takes place at approximately the same temperature when the temperature is allowed to fall. This second critical region (A3) extends over an interval of 25°. Whilst the change A2 is reversible and does not appear to be associated with an alteration in crystalline structure, the change A3 seems to be progressive and (thermo-electrically) non-reversible, and furthermore it is associated with a change in crystalline form.

Strength of Iron at Varying Temperatures.—H. Perrine[3] and C. B. Spencer have investigated the physical properties of steel and cast-iron bars broken at different temperatures, and give a table showing their results. It is suggested that the strength of steel is dependent on its "fibrous" character, the term "fibrous" being used in contradistinction to "granular" as applied to cast iron and not taken too literally. When heated to 260° C. the fibres change their relative positions temporarily, so that if the hot bar be broken, increased strength is exhibited; but on cooling the fibres return to their original position. The same action takes place at above 260° C., but is offset by the weakening effect of the repulsive action of heat on the molecules. The more fibrous the metal, the greater the action of heat in increasing its strength.

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[1] Paper read before the Japanese Institute of Naval Architects; *Engineering*, 1915, vol. xcix. p. 78.

[2] *Journal of the Washington Academy of Sciences*, 1914, vol. iv. pp. 436–440.

[3] *Columbia University; School of Mines Quarterly*, 1914, vol. xxxv. pp. 194–212.

Endurance of Steel under Slow Reversals of Stress.—W. C. Popplewell[1] describes the results of experiments undertaken to ascertain the connection between the elastic phenomena exhibited during slow reversals of stress and the ultimate endurance of steel. His main conclusion is that the application of a number of alternating stresses of equal intensity, from near the primitive limit to somewhere below the yield point of steel, develops artificial limits which have the same value in tension and compression.

Bending Tests.—The original French text of the Carnegie Scholarship report[2] on rotary bend tests, alternating bend tests, and repeated shock tests, by E. Nusbaumer,[3] has appeared.

Impact Tests on Notched Bars.—R. Stribeck[4] has made experiments to test the accuracy of Revillon's tests which yielded the result that the specific work producing rupture in proportional bars (bars of geometrically similar form) was always the same. Upon this law of similarity was based the resolution of the International Association for Testing Materials, passed at the Copenhagen Congress in 1909, which assumed that equal values for the work of impact producing rupture in notched bars of proportional dimensions were always obtained. Stribeck's results obtained with three-centimetre and one-centimetre bars, as used by Revillon, show that this assumption must be accepted with reserve, as the law of similarity by no means held good in his tests. In the case of some of the bars the mean specific work of impact varied as much as 100 per cent.

Transformations of Impact Energy into Heat in Shock-testing.—N. Davidenkoff[5] challenges statements made by C. Mimey[6] and by P. Breuil[7] as to the transformations of impact energy into heat energy during the impact testing of steel. The heating of a test-piece under shock test is susceptible of a very easy explanation. (1) The bulk of the specific energy absorbed on shock is transformed into heat, and (2) the exceedingly brief duration of the process attending shock prevents the heat from being dissipated into the air or conducted to the jaws of the testing machine, as completely as is the case in a test carried out more slowly.

C. Mimey[8] replies to the points raised, and restates his original contentions. Much depends on the definition attached to term "work of deformation." This he regards as the energy expended in producing deformation during an infinitely slow period, whereas

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[1] *Minutes of Proceedings of the Institution of Civil Engineers*, 1913–14, vol. cxcvii. pp. 264–290.

[2] Iron and Steel Institute, *Carnegie Scholarship Memoirs*, 1914, vol. vi. pp. 94–164.

Revue de Métallurgie, *Mémoires*, 1914, vol. xi. pp. 1133–1190.

tahl und Eisen, 1915, vol. xxxv. pp. 392–396.

vue de Métallurgie, *Mémoires*, 1914, vol. xi. pp. 950–954.

d., 1913, vol. x. pp. 1239–1256.

veaux Mécanismes et Nouvelles Méthodes pour l'Essai des Métaux, Paris, 1910.

e de Métallurgie, *Mémoires*, 1914, vol. xi. pp. 954–956.

Davidenkoff regards it as the total energy absorbed by the test-piece, irrespective of the speed of testing.

P. Breuil[1] also replies to the criticisms made.

A. Portevin[2] contributes notes to the discussion of the subject.

The thermodynamic equation relating to a transformation in a system originally in the state 0 to the final state 1, is as follows:—

$$EQ=T_e+(W_0-W_1)+E(U_0-U_1)$$

when E is the mechanical equivalent of the heat; Q the quantity of the heat evolved during the transformation; T_e the external work, that is, the work effected by the forces exerted by the foreign bodies on the test-piece; W_0 and W_1 the *vis vitrix* of the system at the start and at the end, and U_0 and U_1 the original and final internal energies of the system. Introducing the necessary modifications to meet specific cases of stock testing, this leads to the conclusion that the rise in temperature resulting from the transformation of the work into heat depends on the duration of the test, and that, other things equal, it will be greater in a test carried out rapidly than in one carried out slowly.

H. Le Chatelier[3] summarises the conflicting views, which he regards as arising purely from literary differences and not at all from questions of fact, upon which all the disputants are agreed. The confusion of ideas arises solely from the different senses in which the phrase "work of deformation" is employed, and the conclusions differ in what amounts to a metaphysical rather than an actual degree.

Influence of Notches on Strength of Machine Parts.—The influence of the presence of notches on the strength of machine parts is discussed,[4] and reference is made to the work of Heyn on the same subject.

Testing Machines.—U. Forsberg[5] describes the new testing laboratory installed for their own use by the Swedish Waggon Company, Limited. The usual bending tests are made, but the test-pieces for hardened steel made under the international standard were not considered of a suitable dimension. The form of notched bar ultimately used is a round piece turned to 11·5 millimetres diameter, which, after being tempered, is ground to 11 millimetres diameter. A flat is then ground along one side, reducing the thickness at the axis of the section to 10 millimetres. The notch is 1 millimetre deep and in the form of a half circle. The test-bar is of the standard length of 55 millimetres supported on knife edges placed 40 millimetres apart. Another method for bending tests is to turn up ferrules made from the material, which, after tempering, are subjected to a pressure on opposite sides of their circumferences. An ingenious machine is described and illustrated for testing for abrasion. This machine consists of a disc driven in a horizontal position and clothed with emery paper. Over this disc is an arm, centred well back, having a block on it fastened over the disc into which the test-pieces are placed in a vertical position, their lower ends resting on the disc. This arm is arranged to traverse backwards and forwards over the revolving disc, suitable levers and weights giving the pressure. A ratchet arrangement is attached to the test-pieces for the purpose of rotating them slowly as the arm sweeps them across the disc. The disc runs at 300 revolutions per minute, and the arm during that time makes 17½ double strokes across the disc.

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[1] *Revue de Métallurgie, Mémoires*, 1914, vol. xi. pp. 957–958.

[2] *Ibid.*, pp. 959–960. [3] *Ibid.*, pp. 961–962.

[4] *Zeitschrift des Bayerischen Revisions-Vereins*, 1914, vol. xviii. pp. 150–157.

[5] *Bihang till Jernkontorets Annaler*, 1914, pp. 12–35.

T. Y. Olsen[1] describes and illustrates a new form of machine for testing the cutting properties and efficiency of drills, taps, and dies, and cutting-tools generally. It is fitted with a graphic recording mechanism and is capable of affording information which has hitherto been available only as a result of expensive and tedious endurance and other tests.

J. C. Smallwood[2] describes a simple method for testing and calibrating a testing machine.

A brief description[3] is given of the 100-ton universal testing machine at the Glasgow and West of Scotland Technical College and the 300-ton testing machine at Birmingham University. A combined tensile and transverse testing machine for cast iron and an impact-bending testing machine are also shown. The machines were designed by Messrs. W. & T. Avery, Limited.

The economy and efficiency of modern testing machines is discussed,[4] and various types of Avery machines are described and illustrated. An interesting example is the 100-ton testing machine installed at the Glasgow Technical College, which is designed for tensile, compression bending, and shearing tests.

W. O. Lichtner[5] describes a compression machine of 135-ton capacity for testing concrete specimens. The plates between the jaws of the machine will admit a specimen 10 inches square. Eight-inch square specimens can be tested to 3900 lbs. per square inch, and 8-inch round specimens to 5000 lbs. per square inch. The machine has a low initial cost and is of small weight.

An Axial Strainometer.—A. C. Alvarez[6] describes some compression and tension tests on metal and concrete to illustrate the advantage of his elastic deformation measuring device for determining the true elastic limits of these materials. The tests indicate clearly that in the application of so-called axial loading, bending was always introduced, regardless of the precautions taken to prevent it. The strainometer, besides measuring the axial deformation, enables the amount of bending to be accurately calculated.

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[1] *Proceedings of the American Society for Testing Materials*, 1914, vol. xiv. Part II. pp. 541–547.

[2] *Mechanical Engineer*, 1914, vol. xxxiv. p. 442.

[3] *Foundry Trade Journal*, 1914, vol. xvi. pp. 767–768.

[4] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 123–126; *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 665.

[5] *Proceedings of the American Society for Testing Materials*, 1914, vol. xiv. Part II. pp. 535–540.

[6] *Ibid.*, pp. 520–530.

High-speed Tool Steel.—The properties and applications of high-speed tool steel are dealt with.[1] The high-speed steels of the present day are combinations of iron and carbon with tungsten and chromium; molybdenum and chromium; tungsten, chromium, and vanadium; tungsten, molybdenum, chromium, and vanadium. The control of the carbon limits is a very important matter. The best results are obtained from steels containing 0·5 to 0·7 per cent. of carbon. Higher percentages are not desirable, because great difficulty is experienced in forging the steel. With from 9 to 16 per cent. of tungsten and in conjunction with chromium the nature of the steel becomes very brittle, but at the same time the cutting efficiency is greatly increased. Sixteen per cent. of tungsten appears to give maximum hardness. The presence of chromium in high-speed steel varies from 1 to 6 per cent. While a large percentage of tungsten is necessary in a good steel, it has been found that as low as 5 per cent. of molybdenum will make an excellent steel. Molybdenum steels do not require such a high temperature in hardening as do the tungsten steels. The presence of 1 per cent. of vanadium in a high-speed steel, containing at least 18 per cent. of tungsten, enables such a steel to be quenched from a white heat in water without cracking, and this fact led to the recent production of water-hardening high-speed steels; but it must be borne in mind that the percentage of carbon must not exceed 0·6 per cent., otherwise there is danger of cracking in the operation of hardening.

F. C. A. H. Lantsberry[2] presents an historical and general review of the subject of high-speed steels. He also describes an investigation made by him at the works of the Birmingham Small Arms Company, with a view to determining the most suitable steel for the manufacture of milled twist drills. Special experiments were made on the influence of tungsten, chromium, and vanadium upon the drilling properties of high-speed steels, with carbon content as nearly as possible at 0·6 per cent. It was found that a really excellent high-speed steel is that containing 14 per cent. of tungsten and 4 per cent. of chromium, although the author does not claim that this is the best possible combination.

G. G. Bring[3] has followed up Ljungberg's tests on certain drilling steels. Unfortunately, no analyses of the three sorts used are given; but his conclusion is one that will commend itself to most far-seeing men, and that is that the dearer material may well be the cheaper in the long run, taking into account the lesser wear and lesser power required.

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[1] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 142–146.

[2] *Journal of the West of Scotland Iron and Steel Institute*, 1914–15, vol. xxii. pp. 101–124.

[3] *Bihang till Jernkontorets Annaler*, 1914, pp. 371–392.

R. Poliakoff[1] gives the specifications for high-speed tool steels, as adopted by the second Russian Congress of Mining, Metallurgy, and Machine Design, held in St. Petersburg in May 1913. Details of the test-bar are given, together with details and analysis of a normal bar from which the test-piece is made.

T. Schwarz[2] describes an installation in the Royal Dockyards at Kiel for the purpose of testing twist drills, and indicates how, from the data obtained from tests, it is possible to determine the most suitable kinds of steel for the various kinds of work. All the drills used in the experimental work are of high-speed steel 17 millimetres in diameter.

Surface Decarburisation of Tool Steel.—J. V. Emmons[3] has undertaken a number of experiments on the varying degrees of decarburisation resulting from different methods of heat-treating tool steels. The phenomena are found to comply with the following equations:—

$$2Fe_3C+2CO_2=3Fe_2+4CO$$

$$\left.\begin{array}{c} 2CO+O_2=2CO_2 \\ 2CO_2+2Fe_3C=3Fe_2+4CO \end{array}\right\} \text{continuous.}$$

first proposed by W. H. Hatfield.[4] The material subjected to the present experiments contained 1·15 per cent. of carbon. It was exposed to various degrees of heat in different atmospheres, and tables are given showing the degrees of decarburisation corresponding to the different temperatures employed. Curves and photomicrographs of the steel in various stages of decarburisation are given.

Influence of Segregation on Rails.—S. Schukowsky[5] concludes, as the result of many experiments on rails, that the influence of segregation on the quality of rails has been exaggerated. For the removal of pipe and the chief segregated portion of the ingot a discard of 6·25 per cent. is sufficient. He attaches little importance to the Fremont impact test on notched specimens, and recommends that rail specifications should include the shock bending test and a wear test.

Titanium Steel Rails.—G. F. Comstock[6] deals with the effect of titanium on steel. Exhaustive physical and chemical tests have been carried out on forty-two samples of plain and treated open-hearth steel rails. The samples were all taken from the first rails rolled from the ingots, after the usual discards from their tops, thus representing in all cases metal from the top part of an ingot, which would show the greatest amount of segregation and impurities. The samples were always taken in pairs, one treated and one untreated from each rolling, so that in the final comparison the influence of the conditions of manufacture could be as far as possible eliminated.

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[1] *American Machinist*, 1914, vol. xli. pp. 627–628.

[2] *Zeitschrift des Vereines deutscher Ingenieure*, 1914, vol. lviii. pp. 1336.

[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2233–2248.

[4] *Journal of the Iron and Steel Institute*, 1909, No. I. p. 242.

[5] *Génie Civil*, 1914, vol. lxiv. pp. 472–476.

[6] *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. pp. 55–57.

The final averages of the results are tabulated below. Chemical analyses were made at four places on each rail, namely, at top of head, centre of head, web, and flange. The lowest and highest figures for each rail were averaged together, giving the average low and high results:—

	Untreated Rails.		Treated Rails.	
	Low.	High.	Low.	High.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Carbon	0·58	0·82	0·63	0·76
Manganese	0·71	0·78	0·75	0·79
Phosphorus	0·016	0·026	0·018	0·023
Sulphur	0·032	0·058	0·031	0·04
Silicon	0·117	0·131	0·09	0·099

Tests on the head of the rails gave the following results:—

	Untreated Rails.	Treated Rails.
Elastic limit	56,071	59,738
Ultimate strength	118,138	124,857
Elongation	12·8 per cent.	13·1 per cent.
Reduction of area	14·3 ,,	15·4 ,,
Brinell hardness	220	226
Impact resistance (Fremont machine)	1·47 per cent.	1·58 per cent.
Endurance (*A*)	1312	1280
,, (*B*)	16,550,920	23,923,628

(*A*) By Landgraf-Turner machine. Alternate bendings endured before fracture.
(*B*) By White-Souther machine. Revolutions before fracture.

To acquire still more positive data on the effect of titanium on segregation in rails, 79 "A" rails—that is, first rails rolled from the ingots from different untreated heats—were examined by means of sulphur prints, and chemical analyses for carbon made on each at an upper corner of the head, and at the junction of head and web. The average difference between these two points was 17 per cent. for the untreated rails, and the worst rail showed forty; while only twenty-nine of these seventy-nine rails showed less than 12 per cent. For the treated rails the average difference was 3·1 per cent., and the worst one gave 11·5 per cent., none of the thirty-one showing over this amount. Data acquired by the railroads in the United States with regard to the wear of titanium-treated rails as compared with that of ordinary open-hearth rails, show results that are uniformly favourable to the treated rails, in some cases very decidedly so. In axle steel it has been found similarly advantageous to use titanium for purifying the metal and preventing segregation.

G. F. Comstock[1] deals with the occurrence of titanium nitride in steel rails. In the microscopic examination of rails made from steel to which ferro-carbon-titanium has been added, minute, hard, non-metallic spots are often encountered, evenly scattered throughout the rail section and never segregated. When viewed under suitable illumination the spots appear bright pink, and differ entirely from the long thin streaks of manganese sulphide inclusions. Owing to the minute and scattered nature of the spots it is difficult to secure sufficient of the material for analysis, and the problem of its identification was approached by introducing various compounds of titanium into the metal until a substance of similar composition could be found with which to compare it. A process of reasoning by exclusion led to the rejection of the possibility of the pink substance being either sulphide or carbide of titanium, but when rail steel is treated with titanium nitride the substance is encountered, whence it was concluded that the substance itself consists of titanium nitride. Photomicrographs are given showing the nature of these spots in steels of varying degrees of purity, and of varying composition.

The present position of the manufacture of rails from titanium steel is reviewed, and a short summary of some experiences with titanium steel rails in America is given.[2]

Vanadium Steel Rails.—Details of a number of tests on vanadium steel rails have been tabulated and published by the American Vanadium Co. of Pittsburgh.[3] The elastic limit averaged approximately 40 per cent. higher than plain carbon rails, even when the latter contained 50 per cent. more carbon. The ratio of elastic limit to tensile strength is 70 per cent. for vanadium rails as compared with 57 per cent. for carbon steels, and the ductility is also high. The amount of vanadium in the rails ranged from 0·144 to 0·17 per cent.

Testing Conductivity of Steel Rails.—C. H. and N. D. Ridsdale[4] have published tables and data for the testing of steel conductor rails, intended to facilitate the comparison of different standards and the uniform expression of the results obtained. The tables include comparative resistances expressed as "times copper"; resistances of copper standards of various lengths and areas; conversion factors for calculating steel conductivities, (1) by volume and (2) by weight; permissible error and allowances for (1) density and (2) variations in rolling conditions; and data calculated on copper conductivities at different temperatures.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 577–580.
[2] *Railway Age Gazette*, 1914, vol. lvii. pp. 750–751.
[3] *Iron Trade Review*, 1914, vol. lv. pp. 713–716.
[4] *Conversion Factors for the Testing of Steel Conductor Rails*, Middlesbrough, 1913.

American Rail Specifications.—The specifications of the United States Steel Products Company[1] for standard steel rails lay down that the chemical composition of each heat of the steel from which the rails are rolled shall be within the following limits:—

Weight, lbs. per Yard.	45–60.	61–70.	71–80.	81–100.
Acid Bessemer steel—	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Carbon	0·30–0·40	0·35–0·45	0·35–0·45	0·40–0·50
Manganese	0·70–1·00	0·70–1·00	0·70–1·00	0·80–1·10
Silicon (maximum) . .	0·20	0·20	0·20	0·20
Phosphorus (maximum) .	0·10	0·10	0·10	0·10
Basic open-hearth steel—				
Carbon	0·40–0·55	0·40–0·55	0·45–0·60	0·55–0·70
Manganese	0·60–0·90	0·66–0·90	0·60–0·90	0·60–0·90
Silicon (maximum) . .	0·20	0·20	0·20	0·20
Phosphorus (maximum) .	0·04	0·04	0·04	0·04

In the case of the open-hearth steel the manufacturer shall furnish the chemical analysis of each heat of steel covering the elements specified in the table; whilst for acid Bessemer steel the carbon determination for each heat shall be furnished before the rails are shipped, and two analyses every twenty-four hours, one for each day and night shift respectively, covering the elements specified in the table. In both cases determinations shall be made on drillings taken from the ladle test ingot at not less than $\frac{1}{8}$ inch beneath the surface, and the manufacturer may be requested to furnish drillings for check analysis.

The specifications also cover details of manufacture and of mechanical tests.

Tests of Axles.—E. A. Suverkrop[2] gives a table showing the results of tests on three steel railway axles before and after treatment. Photomicrographs are also given showing the segregated condition of the ferrite and pearlite in the untreated steel, and the rearrangement of these constituents caused by the treatment to which the steel was subjected.

High-Nickel Steels.—P. Chevenard[3] points out that the peculiar properties of nickel-steels containing high percentages of nickel make them a class apart from all other steels. He studies the laws of the dilatation of nickel-steels within a wide range of temperatures, and determines and compares the values of the specific volumes of a large number of ferro-nickels at absolute zero, and at a high temperature. The methods and apparatus employed in the research are described in detail and illustrated, the results being embodied in a series of curves plotted from the data obtained experimentally. The first portion of the investigation leads to the conclusions that alloys containing less than 34·45 per cent. of nickel consist of a solid solution of iron and of a compound corresponding with the formula Fe_2Ni; that the reversible and irreversible transformations are phenomena having distinct origins, and are superposable, and that the irreversible transformation, the importance of which depends on the proportion of free iron in solution, disappearing when the proportion falls below a certain amount, is the transformation $\alpha \rightleftarrows \gamma$ of this free iron, influenced in its manifestation by the presence of the iron-nickel compound. Broadly speaking, and taking into consideration ferro-nickels of other percentages, the reversible anomaly, as distinct from the irreversible transformation, appears with its maximum intensity in the vicinity of the formation of the compound Fe_2Ni. It diminishes and disappears altogether when $FeNi_2$ is approached, this compound forming the boundary between the abnormal reversible transformations and those possessing the dilatational peculiarities of nickel. From the researches carried out on the specific volumes of the ferro-nickels the conclusions are drawn that the amplitude of the reversible anomaly is directly proportioned to the amount of the Fe_2Ni compound present in the alloy, while that of the irreversible transformation is proportional to the amount of free iron present in solid solution. Practical conclusions are deduced from these findings.

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[1] *Year-Book of the American Society for Testing Materials*, 1914, pp. 390–403.
[2] *American Machinist*, 1915, vol. xlii. p. 70.
[3] *Revue de Métallurgie, Mémoires*, 1914, vol. xi. pp. 841–862.

Special Steel for Engineering and Structural Purposes.—J. H. Herron[1] deals with the treatment and selection of iron and steel for engineering purposes. The chemical composition of cast iron, wrought iron, and steel is discussed, and the effects produced by the presence of carbon, manganese, phosphorus, sulphur, silicon, chromium, and vanadium are also dealt with.

J. A. L. Waddell[2] discusses the possibilities in bridge construction by the use of high-alloy steel. He first shows what the weights of metal per linear foot of bridge would be for different span lengths when using steel of various elastic limits ranging from that of ordinary carbon steel up to 100,000 lbs. per square inch, and then demonstrates the comparative economics of finished bridges built of alloy steels of the several assumed elastic limits, and of those built of carbon steel. Hitherto the author has not been able to procure from steel manufacturers a nickel-steel of a guaranteed elastic limit over 50,000 lbs., but he intends to obtain material with an elastic limit of 60,000 lbs. for his next undertaking.

In the discussion N. Petinot[3] describes experiments in the manufacture of alloy steels, and in particular refers to the treatment of steel with titanium. G. L. Norris[4] believes that to produce steel having an elastic limit of 100,000 lbs., recourse will have to be had to vanadium alone, or to vanadium with chromium. He gives instances of tests on vanadium-chromium steels which have shown an elastic limit of 125,000 lbs., tensile strength 145,000 lbs., and elongation 18 per cent. A number of other results of tests on vanadium steels are quoted. Other speakers deal with the engineering aspect of the question.

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[1] *Journal of the Cleveland Engineering Society* (U.S.A.), No. 7, pp. 101–130.

[2] *Proceedings of the American Society of Civil Engineers*, 1914 (*Papers and Discussions*), vol. xl. pp. 663–700.

[3] *Ibid.*, pp. 1624–1627.

[4] *Ibid.*, pp. 2342–2348.

F. Bohny[1] also discusses the advantages of the use of high-grade steel for bridge building.

Some data are given[2] on the properties of vanadium steel covering its chemical composition and physical properties, and the advisability of using vanadium steel in long span bridges is discussed.

In connection with its investigations in the iron and steel industry, the United States Bureau of Mines[3] is studying the methods of producing alloy steels, such as are required in mining and milling equipment. The object of this study, which is being conducted by H. D. Hibbard, is to ascertain what losses now attend the manufacture of these steels, and to determine how efficiency in their production can be increased.

J. Dewrance[4] deals with the standardisation of pipe flanges and flanged fittings. The Committee appointed by the Engineering Standards Committee to deal with this question have standardised flanges in four classes, namely: (1) low-pressure standard, (2) intermediate pressure standard, (3) high-pressure standard, and (4) extra high-pressure standard. As regards thickness of flanges, the author is of opinion that two separate stresses have to be studied, the first distorting the flange and the pipe considered as a cantilever, and the second cupping the flange itself.

Use of Iron Sleepers in Tropical Climates.—Some interesting notes concerning the respective durability of wood and iron sleepers on railways in tropical climates are given.[5] Results of experiences obtained in Africa, China, India, and Java are reviewed.

Influence of Mechanical and Thermal Treatment on Properties of Steel Tubes.—In view of the difference in the behaviour of hard-drawn steel tubes, before and after annealing, under stress, F. E. Rowett[6] has carried out some experiments on elastic properties. At a suitable temperature a hard-drawn tube, which contains a good deal of amorphous material, behaves like a viscous fluid, that is, it flows more or less freely under stress, whereas at the same temperature an annealed tube being crystalline will flow in a much less degree, corresponding to the small amount of amorphous material in it. At a temperature of 300° C. a hard-drawn tube shows properties similar to those of pitch at ordinary temperatures, or of glass at a temperature rather below its softening point. It is still highly elastic under rapidly varying stress, but flows perceptibly when the stress is applied for a long time. On the other hand, in the annealed tube at 300° C., the energy dissipated in a cycle of stress is still almost independent of the time taken over cycle. At a higher temperature—for example, at 540° C.—the hard-drawn tube flows rapidly, and continues to flow for a long period, though at a diminishing rate, under a shear stress of less than one ton per square inch. Moreover, like pitch or glass, the steel at this temperature shows considerable elastic after-working. If the stress be suddenly removed the immediate elastic recovery is followed by a slow backward flow, which persists for many minutes.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 47–48.

[2] *Engineering Contract*, 1915, vol. xlii. pp. 495–496.

[3] *United States Bureau of Mines; Annual Report for the Year ending* June 30, 1914, p. 92.

[4] Paper read before the Institution of Mechanical Engineers, January 22, 1915.

[5] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1386–1387.

[6] Paper read before the Royal Society, March 4, 1915; *Chemical News*, vol. cxi. p. 142.

Steel for Locomotive Fire-boxes.—E. Meyer[1] advocates the use of mild steel for the construction of locomotive fire-boxes, as it has become desirable, on account of the scarcity of copper due to the war, to find a suitable substitute. In America steel is now exclusively used for that purpose, and as the requisite conditions of the specification for such material can easily be fulfilled by German manufacturers, there is no reason why steel should not permanently be employed in future by German locomotive builders.

Failure of Ship Plates.—W. J. B. Wilson[2] deals with the remarkable failure of a consignment of steel ship plates. The material had been tested and passed by Lloyd's, and notwithstanding that it filled all the requirements of the rules as regards testing, it failed entirely to stand the ordinary work of the shipyard, cracks appearing round the rivet holes after they had been riveted. The plates were examined by J. O. Arnold, who states that the material appears to have been overheated in the manufacture, and gravely injured in the operation. A number of alternating stresses which were made gave extremely unsatisfactory results. Whereas good mild steel should endure a minimum of 300 alternations of stress, the faulty steel in eight tests averaged only about one-third of this, or 100 alternations.

Tests of Chilled Wheels.—F. K. Vial[3] presents the results of an extended investigation of the standardisation of chilled iron wheels for cranes. The vertical load to be carried on any wheel is not limited by the capacity of the wheel, but by the carrying capacity of the rail. The bearing power of chilled iron is far in excess of that of a steel rail, and therefore may be neglected when considering maximum vertical loads. The tests show that under like loads the depression in the rail is inversely as the diameter of the wheel. The larger diameter of wheel makes a larger area of contact, which reduces the pressure per square inch.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 396–398.

[2] Paper read before the North-East Coast Institution of Engineers and Shipbuilders, November 27, 1914; *Mechanical Engineer*, 1914, vol. xxxiv. pp. 467–469.

[3] *Journal of the American Society of Mechanical Engineers*, 1915, vol. xxxvii. pp. 147–151.

With regard to the carrying capacity of various rails, tables are given to show that on a new A.S.C.E. rail the safe maximum limiting load for a 12-inch wheel is 23,000 lbs., and for a 33-inch wheel, 38,150 lbs.

The tests show that every ⅛-inch added to flange thickness, with the relative increase in tread thickness, increases the flange strength 25 per cent.

Material for Motor-Car Construction.—F. Nicholson[1] refers to the necessity of widely varying physical properties of the alloy steels used in motor-car construction on account of the various duties imposed upon them, and puts forward a suggestion that instead of the several alloys that are usually kept in stock, a simple nickel-steel could by suitable varying treatment be made to replace any one of the several alloys now in use.

R. Moldenke[2] discusses the qualities of malleable iron best suited for use in the construction of automobiles, and describes how these qualities can best be obtained.

Tests of Ball Bearings.—F. H. Colvin[3] describes the inspection and testing of ball bearings at the works of the Hoffman Manufacturing Company, Limited, Chelmsford.

H. Hermanns[4] describes the inspection and testing of ball bearings in a German factory.

Manufacture and Properties of Manganese Steel.—J. H. Hall[5] deals with the composition and characteristics of manganese steel, its properties and uses, the method of manufacture, heat treatment, and its metallography.

Chemical and Mechanical Relations of Iron, Cobalt, and Carbon.—J. O. Arnold[6] and A. A. Read have investigated the chemical and mechanical relations of iron, cobalt, and carbon, the results being given in a series of tables. Five ingots were melted by coke in white crucibles from pure "Thermit" cobalt, Swedish bar iron and Swedish white iron, all charged together, and small quantities of pure metallic manganese and aluminium were added ten minutes before teeming. From the results of the dynamic mechanical tests the authors consider that it may reasonably be deduced that, with equal carbons, the tenacity of the steels, as measured by the yield points and maximum stresses, increases with the cobalt, while the ductility, as measured by the elongation per cent., correspondingly falls. The results of the determination of the carbides show that practically the total amount of carbon in each steel was accounted for, the very small loss being to a considerable extent due to the difficulty of getting the bars absolutely clean, and thus obtaining the last trace of carbide. With steels high in carbon, and containing up to 20·85 per cent. of cobalt, the carbide Co_3C exists in very small proportions, only about 5 to 6 per cent. of the total cobalt present in the steel being found in combination with the carbon as carbide, the remaining 94 to 95 per cent. being alloyed with the iron and manganese. The bars were annealed by heating in a gas-fired furnace for a period of about eight hours, until an even temperature of about 780° C. was obtained, soaked at this heat for one hour, the furnace dampered down, and the steel allowed to cool over a period of about twenty-four hours. The results show that, on well-annealing a cobalt steel with 0·64 per cent. of carbon and 2·68 per cent. of cobalt, only a trace of graphite is found. As the percentage of cobalt increases in the next member of the series, a large amount of graphite is precipitated, while in the three remaining steels, with still higher percentages of cobalt, the whole of the carbon is precipitated in the graphitic condition. The authors compare the behaviour of cobalt with nickel in steel. This comparison is interesting, in view of the fact that nickel and cobalt have been commonly considered to be identical in their properties.

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[1] *American Machinist*, 1915, vol. xlii. p. 115.

[2] Paper read before the American Society of Automobile Engineers, New York, January 6–7, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 146–148.

[3] *American Machinist*, 1914, vol. xli. pp. 793–795. [4] *Ibid.*, pp. 837–841.

[5] *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. pp. 57–60.

[6] Paper read before the Institution of Mechanical Engineers, March 19, 1915; *Mechanical Engineer*, 1915, vol. xxxv. pp. 282–284.

Influence of Boron on Steel and Cast Iron.—Some experiments have been made in the laboratory of the Electro-chemical works,[1] Bitterfeld, to investigate the influence of boron on mild steel and cast iron. Four mild steel ingots were prepared, containing 0, 0·2, 0·4, and 0·8 per cent. of boron respectively, and their characteristics and properties were compared. The first noticeable effect was the great increase in the pipe of the ingots containing boron. It increased regularly with the additions of boron until, at 0·8 per cent., it was 45 per cent. larger than in the ingot with no boron. The brittleness also rose rapidly as the boron was increased. At 0·2 per cent. the steel became difficult to forge, and was quite red-short at 0·8 per cent.

Heat treatment reduced the brittleness somewhat, but not enough to confer useful strength. As an alloy metal for steel, boron is therefore of little practical utility.

Four cast iron bars were then prepared with the same proportion of boron as above. In this material, too, a great increase in the hardness and brittleness took place, in proportion to the increase of the boron. With 0·4 per cent. the piece could not be machined with ordinary tools, and at 0·8 it was glass-hard and so brittle that it could be pounded in a mortar. The structure was also entirely altered; the grain disappeared entirely, and the fracture appeared almost white. The separation of graphite is restricted, and the formation of carbides is strongly favoured.

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1530–1531.

G. Hannesen[1] discusses the manufacture of boron steels. After giving the analysis of ferro-boron, the phase diagram of iron-boron alloys, with boron ranging from 0 to 8·5 per cent., is considered, together with remarks on the ferro-magnetism and hardness of boron steels. In their thermal behaviour and structure they show remarkable analogies with carbon steels, but there are some differences. The existence of the compound Fe_5B_2, as the richest iron boron combination, was confirmed, and its melting point was determined at 1351° C.

Influence of Heat Treatment on Magnetic Properties of Iron and Steel.—R. L. Sanford[2] has carried out magnetic measurements at different temperatures within the atmospheric range on wrought iron, cast iron, and low-carbon steel with different heat treatments, and from the results of his investigation he concludes that the temperature coefficient of magnetic permeability, though small, cannot be neglected in magnetic measurements of high accuracy. On account of the wide variation in temperature coefficient, not only for different materials but also for the same material with different heat treatments, correction cannot be made to standard temperature from data obtained from other materials. Unless the temperature coefficient is known for the particular material under test, temperature control offers the only means of avoiding the error due to temperature changes, at least where errors as great as 1 per cent. are to be avoided.

F. C. Langenberg[3] and R. G. Webber describe the results of some experiments on the structure and hysteresis loss in medium-carbon steels, which arose out of some magnetic investigations on steel containing 0·43 per cent. of carbon. Six bars were tested, four of which were pearlitic and two sorbitic. The former showed a rise in their hysteresis loss, with decreasing grain size, the residual and the coercive force increasing. A pearlitic bar showed an increase in the hysteresis loss of approximately 50 per cent. From this it is concluded that in magnetic testing careful attention must be given to the internal structure of the metal undergoing test. A mere statement of its condition as hardened or unhardened, annealed or tempered, is useless and often misleading. It may be inferred that a minimum hysteresis loss can be obtained by the combination of large grains with coarsely laminated pearlite. Photomicrographs of the structure of the steels employed, and diagrams of the hysteresis losses are given.

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[1] *Zeitschrift für anorganische Chemie*, 1914, vol. lxxxix. pp. 257–258.

[2] United States Bureau of Standards; *Journal of the Franklin Institute*, 1915, vol. clxxix. p. 96.

[3] *Bulletin of the American Institute of Mining Engineers*, 1915, pp. 291–300.

Magnetic and Mechanical Properties of Pure Electrolytic Iron.—B. Neumann[1] reviews recent investigations of the magnetic and mechanical properties of pure electrolytic iron, and gives tables of the results both of magnetic and mechanical tests.

Magnetic Properties of Alloy Steels.—J. A. Mathews[2] has investigated the magnetic properties of hardened alloy steels, and finds that they vary with the physical characteristics of the metal. Alloys hardened by quenching in oil give a lower permeability and residual magnetism, but a higher coercive force than those quenched in water. The size of the cross-section of the metal also has an influence, varying according to the hardness of the metal.

Magnetic Properties of Manganese Steel.—A. Sauveur[3] criticises the recent work of B. Hopkinson[4] and Sir R. A. Hadfield on non-magnetic and magnetic conditions of manganese steel, and their conclusions as regards the allotropic theory. A consideration of the results leads to the belief that they can be satisfactorily explained in the light of that theory, and are inexplicable in any other way. Experiments with fresh samples of manganese steel containing 1·25 per cent. of carbon and 12·5 per cent. of manganese have confirmed this view. It would appear that manganese steel of the Hadfield type may occur under three distinct conditions: (1) as austenitic steel mixed with a considerable amount of free carbide, when slowly cooled from above 700°; (2) as austenitic steel practically free from segregated carbides, when rapidly cooled from a high temperature; and (3) as martensitic, or possibly austenito-martensitic steel, obtained by reheating austenitic steel for a sufficient length of time at a temperature between 500° and 700°. In the first condition the metal is non-magnetic, weak, and has a hardness number of about 200; in the second, possesses high tenacity, is non-magnetic, and has a hardness number of about 180; while in the third it is ferro-magnetic, owing to the presence of some α-iron, and its hardness varies between 250 and 350, owing to the presence of β-iron.

Steel for Permanent Magnets.—S. P. Thompson[5] states that, for a steel suitable for the making of permanent magnets, the prime requisites are that it shall have a large remanent magnetisation and high coercive force. These two qualities are independent of any question as to form. According to all evidence to the present time, the coercive force of any given specimen of steel is independent of the form, provided that it has been subjected to a sufficiently great magnetising force, the self-demagnetising coefficient affecting the degree of remanent magnetisation, but not affecting the degree of coercion with which that residuum is held by the steel. When any specimen of steel is subjected to a cycle of magnetisation so as to obtain its hysteresis loop, the dimensions of the loop, providing the maximum magnetising force was sufficiently great to enable a practical saturation to be attained during the magnetising process, suffice to form a judgment as to its suitability for the purpose of making permanent magnets.

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1637–1638.

[2] *Proceedings of the American Society for Testing Materials*, 1914, vol. xiv. Part II. pp. 50–71.

[3] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2439–2449.

[4] *Ibid.*, 1914, pp. 513–530.

[5] Paper read before the Physical Society; *Electrician*, 1915, vol. lxxv. pp. 65–66.

J. F. Henderson[1] deals with magnet steel. He states that magnet steel usually contains tungsten, and the hardening process was one which required great care, since magnets must always be very hard, but not necessarily glass-hard. For instance, if a long and short magnet were made of the same steel, the short magnet must be made rather harder than the long one to get equally good results out of each. The two qualities required in a magnet were high magnetisation and permanence.

Conductivity of Alloys in the Liquid Condition.—K. Bornemann[2] and K. Wagenmann have continued their investigation of the electric conductivity of metal alloys in the liquid condition. A diagram is given for the conductivity and temperature coefficients of alloys of varying concentrations.

Apparatus for Determining Hysteresis and Eddy Loss in Sheet Iron.—A description is given[3] of an apparatus for determining the hysteresis and eddy losses of sheet iron and steel, the core loss being read directly on a wattmeter.

Magnetic Susceptibility of Iron Compounds.—K. Honda[4] and T. Soné have examined the influence of temperature on the magnetic susceptibility of hæmatite, magnetite, chromium trioxide, and chromium sesquioxide over the range −170° to 1300°. From the susceptibility-temperature curves of the iron compounds, the authors draw the conclusion that hæmatite shows no change of structure up to 1300°, and that it contains a small quantity of magnetite at temperatures above −40°. If magnetite be heated in air at 1300°, it is almost completely converted into hæmatite. Chromium trioxide appears to undergo two changes, whereby the oxide, Cr_6O_{15}, is formed at about 290°, and Cr_2O_3 at about 420°. The curve for chromium sesquioxide indicates that no change of structure occurs up to 1300°.

Detection of Phosphorus Segregations in Steel.—J. E. Stead[5] gives a concise description of the various methods, published by himself and others, for the detection of local segregations of phosphorus in steel and iron. The methods described are as follows: (1) The heat-tinting process. (2) The aqueous picric acid method. (3) Etching by strong nitric acid (10 per cent. acid and 90 per cent. water). (4) Etching by aqueous solution of copper ammonium chloride. (5) Feeble attack by dilute acid reagents. (6) The hardening, tempering, and etching method. (7) "Ghost Lines," an indication of local concentration of phosphorus. (8) Etching with acidulated alcoholic solution of copper chloride. (9) Rosenhain and Haughton's method for etching mild steel. (10) Brearley's modification of Rosenhain and Haughton's method. (11) Whiteley's method.

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[1] Paper read before the Institution of Automobile Engineers, February 10, 1915.

[2] *Ferrum*, 1914, vol. xi. pp. 330-343.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 478.

[4] *Science Reports of the Tohoku Imperial University*, 1914, vol. iii. pp. 223-234.

[5] *Proceedings of the Cleveland Institution of Engineers*, Session 1914-15, pp. 73-82.

Physical and Chemical Properties of Metals at High Temperatures.—O. Ruff[1] and W. Bormann have carried out a series of investigations on metals at high temperature ranges. (1) Manganese and carbon. The report describes the measurement of the temperatures, the type of furnace, the methods of analysis, the solubility determinations, and the boiling points of the manganese saturated with carbon, and of the pure metal. The temperature-concentration diagram of the manganese-carbon system is completed. (2) Nickel and carbon. The boundary between the pure melted metal and the pure metal with mixed crystals is defined, and the boiling point of pure nickel and nickel saturated with carbon is determined, together with the composition of the vapours. (3) Iron and carbon. The solubility line B D H Y in the phase diagram is plotted, and the boiling temperature of pure iron and of iron saturated with carbon, and the composition of the vapours are determined. (4) Cobalt and carbon have been investigated in similar respects by O. Ruff[2] and F. Keilig.

Solubility of Slag Inclusions.—F. Giolitti[3] and G. Tavanti discuss the alleged solubility of slag inclusions in molten steel. They have examined specimens of acid and basic steel that had been suddenly cooled from the fused condition, annealed, and slowly cooled respectively, and find that in both kinds of steel the appearance, number, and size of the slag inclusions were not appreciably modified by the different treatments. This result excludes the possibility of the slag being dissolved by the molten steel as affirmed by Ziegler. S. Steinberg,[4] in experiments with artificial inclusions of sulphides of iron and manganese, found that inclusions in specimens of steel quenched from the liquid state were many times smaller than in similar specimens annealed after such quenching. This result, which is quite at variance with the results obtained by the author in the case of "reaction slags," indicates that the latter are not, as commonly supposed, composed mainly or entirely of manganese sulphide.

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[1] *Zeitschrift für anorganische Chemie*, 1914, vol. lxxxviii. pp. 365–409.

[2] *Ibid.*, pp. 410–423.

[3] *Annali di Chimica Applicata*, 1914, vol. ii. pp. 360–366.

[4] *Revue de la Société russe de Métallurgie*, 1913, vol: i. pp. 514–521.

Composition of Shell Steel.—Fragments of French, English, and Russian shells picked up on battlefields have been analysed and subjected to micrographic examination at the metallographic laboratory of the Charlottenburg High School.[1] The structures for the most part consisted of fine-grained pearlite and ferrite, but there were local differences in the size of the grain, which clearly pointed to a strong cold-working effect. All the specimens except the Russian show an unusual amount of slag enclosures, so much so as to give the impression at first that the material was wrought iron. However, the percentage of manganese and the homogeneity of the internal structure left no doubt that it was steel, and the slag merely indicated that the operations had been greatly hurried. The chemical composition was as follows:—

.	C per Cent.	Mn per Cent.	Si per Cent.	P per Cent.	S per Cent.	Cr per Cent.	As per Cent.
French shells . .	0·54	0·68	0·32	1·170	0·030	...	0·05
British ,, . .	0·47	0·76	0·31	0·056	0·040	...	...
,, ,, . .	0·45	0·76	0·21	0·053	...	...	...
,, shrapnel .	0·60	0·90	0·07	0·054	0·024	...	...
,, shells . .	0·36	0·70	0·21	0·034	0·040	0·25	...
Russian ,, . .	0·58	0·55	0·24	0·025	0·024	0·16	...

None of the fragments contained any nickel.

Measurement of Gases in Iron.—P. Goerens[2] and J. Paquet have devised a method for the measurement of the gases contained in iron. It consists in melting iron, rendered easily fusible by the addition of tin and antimony, under vacuum, and drawing off the gases by means of a Sprengel's mercury pump. The mode of procedure much resembles that of Baraduc-Muller,[3] described elsewhere.

Damascene Steel.—P. Oberhoffer[4] publishes a note on the structure of damascene steel, and offers an explanation, based on the physical characteristics of the material, of the cause of surface markings which are peculiar to the genuine product. The note is accompanied by micrographs in illustration of the author's own investigation.

Metallography.—L. Guillet[5] deals with the practical applications of microscopic metallography in industry, and gives a table showing the various indications met with on (1) unpolished sections, (2) polished sections, and (3) polished sections which have been subject to the attack of etching mediums, the conditions to which these indications correspond, and the treatment they reveal.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 170–171.
[2] *Ferrum*, 1914–15, vol. xii. pp. 57–64, 73–81.
[3] *Carnegie Scholarship Memoirs*, 1914, vol. vi. pp. 216–230.
[4] *Stahl und Eisen*, 1915, vol. xxxv. p. 140.
[5] *Comptes Rendus de la Société de l'Industrie Minérale*, 1914, pp. 312–316.

H. B. Pulsifer[1] gives some notes on metallography. He discusses the nature of ferrite, and defines the structural grain. He also describes a shock-proof microscope frame used at the Armour Institute of Technology.

B. Strauss[2] in a lecture before the German Society of Chemists gives a general review of the microscopic method of the investigation of steel and steel alloys. The lecture is illustrated by means of numerous typical photomicrographs, including a series of coloured micrographs.

P. Oberhoffer[3] gives a summary of recent metallographic research work, and of the progress in the practical application of metallography.

W. Guertler[4] discusses Belaiew's studies on the structure of steel.

Etching Reagents.—O. F. Hudson[5] gives a description of the principal reagents used in determining the microscopic structure of metals and alloys. He deals generally with the preparation of the specimen, in order to bring it to a condition suitable for etching. The different etching reagents and the methods of developing the structure are described in some detail, and a summary is given containing a list of metals and alloys, and the etching reagents suitable for them. Chief prominence is given to the etching reagents used for non-ferrous metals and alloys, but the most important of those used for iron and steel are dealt with briefly.

Metallographic Tests of Iron and Steel.—The American Society for Testing Materials gives[6] standard methods for metallographic tests for iron and steel.

O. W. Storey[7] gives an account of the considerations involved in deciding the structure of a steel, and the means of detecting and understanding that structure by the microscope. He describes a predominating defect of much cast steel as "ingotism," by which is meant the formation of large crystals, which is liable to occur when the metal is cast at too hot a temperature or cools too slowly during solidification. Microstructures of specific instances of failure from various causes are given.

J. H. Whiteley[8] deals with the formation of two entirely different structures in a cogging-mill steel guide as revealed by micrographical examination, and suggests as a reason for the phenomenon that bottom-filled ingots give better results in the rolled material than top-poured ingots.

[1] *Chemical Engineer*, 1914, vol. xix. pp. 186–191.

[2] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1814–1820.

[3] *Ibid.*, pp. 1853–1855, 1888–1890.

[4] *International Journal of Metallography*, 1914, vol. vi. pp. 72–89.

[5] *Journal of the Institute of Metals*, 1915, No. 1, pp. 193–221.

[6] *Year-book of the American Society for Testing Materials*, 1914, pp. 364–366.

Iron Trade Review, 1914, vol. lv. pp. 817–819.

Proceedings of the Cleveland Institution of Engineers, Session 1914–15, pp. 50–72.

Microstructure of Electrolytic Iron.—O. W. Storey[1] has carried out a microscopic study of electrolytic iron. The deposits were crystalline, but variable in character, and frequently resembled the minerals manganite, hæmatite, and limonite in structure. On heating to 910°–915° C. the crystalline structure of the deposit was converted into the grain structure of ordinary ferrite, the grain being large or small as the original deposit was coarse or fine; but no change occurred below the A3 point. By long annealing at the Ac3 point the coarse-grained ferrite structure became somewhat finer, but never so fine as that resulting from a fine-grained deposit. The grains of electrolytic iron did not grow appreciably at 1150° C. The ferrite grains of fused electrolytic iron were composed of smaller grains, the boundaries of the latter being merely shallow depressions, whereas those of the former were V-shaped grooves. There was a continuity of inner grain structure between merging grains of similar crystal orientation, and this inner structure was only destroyed by several annealings above the Ac3 point. The inner grains are probably groups of similarly orientated iron crystals, the orientation in all the grains being alike throughout the ferrite grain; and the large γ-grains formed during the slow cooling of the molten metal contain numerous, similarly orientated non-γ nuclei, and are changed to the non-γ state without altering in size. The microstructure of rolled electrolytic iron consisted of clean ferrite, and that of the forged metal of fine-grained ferrite containing a minimum of impurities.

Causes of Hardening of Steel.—J. C. W. Humfrey[2] explains the formation of the hard amorphous solution of α-iron and iron carbide (comparable with Beilby's amorphous phase formed by over-strain) to which the hardness of quenched carbon- or normally cooled alloy-steels is due, on the assumption that in the passage of a substance from one allotropic modification to another of different crystalline form, as at the Ar3 point in steels, a temporary amorphous phase is produced corresponding to the liquid phase of the modification about to be formed; and that owing to sudden cooling or to the presence of certain alloyed elements, whereby the change point is lowered to a temperature at which crystallisation in the viscous mass becomes difficult, the amorphous phase is retained in a metastable form in the cold.

Specific Volume of Iron-Carbon Alloys.—M. Levin[3] and K. Dornhecker have investigated the specific volume and the hardness of iron-carbon alloys. The densities of a series of very pure iron-carbon alloys were determined. The influence of annealing on the density is not noticeable with carbon concentrations from 0 to 1 per cent. Above 1 per cent. the specific weight decreases, due to the formation of temper carbon. A relation between the specific weight and the annealing temperature was found to exist in alloys containing over 1 per cent. of carbon. The hardness determinations agree in general with the results of previous investigators.

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[1] *Transactions of the American Electro-chemical Society*, 1914, vol. xxv. pp. 489–527.
[2] *Transactions of the Faraday Society*, 1915, vol. x. pp. 240–247.
[3] *Ferrum*, 1914, vol. xi. pp. 321–329.

Iron-Manganese System.—G. Rümelin[1] and K. Fick have investigated the iron-manganese system. The δ-γ transformation of the iron was detected, δ-iron forming with manganese mixed crystals, which at 1455° C. contain about 2 per cent. of manganese as a maximum. Melts with over 13 per cent. of manganese solidify direct to a continuous series of mixed crystals of manganese and γ-iron. The points A3 and A2 on the pure iron curve can be detected on curves for alloys containing from 0 to 50 per cent. of manganese.

Allotropy.—A. Smits[2] and S. C. Bokhorst give a number of experimental methods of proving their theory of allotropy. These all depend upon the effect of a previous treatment on the physical properties of such substances as come within the scope of the theory.

A. Smits[3] discusses the application of the theory of allotropy to the electro-motive equilibrium between a metal and an electrolyte, and shows that a metal which exists in allotropic forms is made up of different kinds of molecules, and sends various kinds of ions into the solution. The diagram representing this equilibrium is that of a pseudo-system, which in the present consideration has been regarded as a pseudo-binary system. The development of this idea in connection with electrolysis leads to possible explanations of why in electrolysis it is, in many cases, the metastable and not the stable form of a metal which is deposited. It is also shown that with a definite current density the metal forming the anode becomes more electro-negative, whilst at the same time the cathode metal becomes less electro-negative, at least so far as their surface layers are concerned. The reason is offered for the fact that, when a metal is brought into contact with a solution of one of its salts, an increased rate of setting up the internal equilibrium is observed. The theory of allotropy leads to the view that when a metallic compound is reduced to metal at the lowest possible temperature, a product will be obtained which is far removed from its internal equilibrium, and which consequently will show an abnormal chemical activity. This state of things is probably the explanation of the remarkable behaviour of pyrophoric metals.

Specific Heat of Metals.—E. H. Griffiths[4] and E. Griffiths state that while the specific heats of a large number of substances have been measured at the ordinary temperature, and also at liquid air and liquid hydrogen temperatures, no direct measurements of the true specific heats at intermediate temperatures have been made. They have therefore worked out a method for maintaining the temperature of an enclosure constant at any point between that of the room and −165° by a direct application of the Joule-Thomson effect. The method employed in the measurement of the specific heats of metals depends on the determination of the rise in temperature of a block of the metal which is suspended in the constant temperature enclosure and supplied with a measured quantity of electrical energy.

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[1] *Ferrum*, 1914–15, vol. xii. pp. 41–44.
[2] *Zeitschrift für physikalische Chemie*, 1914, vol. lxxxviii. pp. 608–621.
[3] *Ibid.*, pp. 743–757.
[4] *Philosophical Transactions*, 1914 (A), vol. ccxiv. pp. 319–357.

Cooling Curve of Nickel.—Baikow[1] has obtained a cooling curve of nickel heated in a vertical electric furnace, temperatures and temperature-differences being simultaneously registered photographically, copper being used as the neutral body. A slight break was obtained on the difference curve at 360° C., agreeing with the known magnetic transformation of nickel at 340° C.

Reduction of Iron by Platinum.—R. B. Sosman[2] and J. C. Hostetter deal with the reduction of iron oxides by platinum. They show that platinum acts on both hæmatite and magnetite at 1200° under low pressures of oxygen, absorbing iron and giving off oxygen. It also reacts with magnetite in the same way at 1600°, and at the usual atmospheric pressure of oxygen.

Electrolytic Iron.—O. P. Watts[3] and N. H. Li describe the results of experiments on the electro-deposition of iron so far as it is influenced by the addition of foreign materials to the bath. An electrolyte containing only chlorides gives a much smoother deposit than one consisting of sulphides of iron and ammonia, but the resulting iron rusts so badly that a pure chloride electrolyte is not practicable. The admixture of some chloride with the sulphate electrolyte improves the smoothness of the deposit without causing excessive rusting of the iron produced. Ammonium oxalate and formin are capable of improving the quality of the deposits.

Formation of Alloys by Electrolysis.—G. Bruni[4] and M. Amadori have experimented on the formation of alloys by electrolysis, and state that on electrolysing solutions of mixed salts of two metals (Cu—Ni, Fe—Ni, Fe—Co, Ni—Co) capable of forming solid solutions in all proportions, the deposits contained the two metals in proportions varying with the composition of the solution and with the current density and voltage. With moderately high current density and voltage the ratio between the two metals in the deposit was, in general, approximately the same as in the solution, but with low current density and voltage a larger proportion of the less electro-positive metal was deposited. In the case of nickel and iron, using low current density (0·05 ampere per square decimetre), solutions in which the proportion of iron varied from 40 to 75 per cent. yielded deposits in which the iron content was practically constant at 52 per cent. Solutions of iron and cobalt salts, in which the proportion of iron varied from 33 to 50 per cent., also yielded deposits of constant iron content.

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[1] *Journal of the Russian Physical and Chemical Society*, vol. xlii. pp. 1380–1381; *International Journal of Metallography*, 1914, vol. vi. p. 115.

[2] *Journal of the Washington Academy of Sciences*, 1915, vol. v. pp. 293–303.

[3] Paper read before the American Electro-chemical Society; *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 343.

[4] *Atti della R. Accademia di Scienze, Lettere ed Arti*, Padova, 1913–14, vol. xxx. p. 349; *Annali di Chimica Applicata*, 1915, vol. iii. p. 147.

Corrosion of Iron.—S. H. Ellis[1] describes the corrosion of the steel wharves at Kowloon, which are situated on the mainland side of Hong-Kong harbour. In 1906, in connection with the reconstruction of a wharf, an examination was made of some steel-joist piles which had corroded in a curious manner. Any steel immersed in sea water in the district becomes quickly coated with barnacles and with a dense vegetable growth. It had been an accepted theory that this growth protected the metal. It was found, however, that a large number of pits had formed in the surface of the steel, varying in size up to 1¼ inches in diameter and ⅜-inch deep. They were found to be full of sulphide of iron. Apparently, some marine growth attached to the piles produces large quantities of sulphuretted hydrogen when decaying. It was eventually decided to encase the whole of this structure in cement, leaving certain other wharves with bare steel, which was painted with an anti-corrosive composition on erection. Since 1908, when the work was completed, the superstructure and the piles above low-water level have been scraped and painted annually, and the steel has been kept in fair condition, with no marked deterioration. Two years after completion pitting had commenced, and in 1913 this corrosion had developed to a serious extent. In the same year obvious indications of corrosion within were apparent on the surface of the concrete. Thorough examination of the whole structure revealed that above high-water level corrosion appeared to have gone on almost unchecked by the presence of the concrete covering, and a thickness of about $\frac{1}{16}$ in. of rust-scale was found on all steel members in this zone on their under and outer sides. Although the workmanship was not everywhere good, the author was forced to the conclusion that even when perfectly encased in a 2½-inch covering of sound, homogeneous concrete, the steel was not protected against the effect of excessively damp, salt air in that climate.

J. Newton Friend[2] and C. W. Marshall describe experiments carried out in order to ascertain the minimum quantities of alkali required to inhibit the corrosive actions of different salts, and to discover whether or not any relationship exists between these quantities and the relative strengths of the acids and bases constituting the salts. The amounts of sodium carbonate, expressed as cubic centimetres of N solution per 10 cubic centimetres of liquid, required to inhibit corrosion by salt solutions at different concentrations are shown in the following table:—

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[1] Paper read before the Institution of Civil Engineers, December 1, 1914.

[2] *Transactions of the Chemical Society*, 1914, vol. cv. pp. 2776–2782.

Sodium Salt.	N.	N/2.	N/2·5.	N/3·3.	N/4.	N/5.	N/10.	N/17.	N/20.	N/100.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Chloride . .	...	...	16·0	...	...	8·0	...	...	2·7	1·05
Nitrate . .	10·0	7·6	5·6	...	...	3·6	...	...	1·45	0·75
Sulphate . .	4·8	3·2	2·8	...	...	2·4	...	...	1·40	0·80
Fluoride . .	...	1·4	...	...	1·4	...	1·4	...	1·05	0·75
Sulphite . .	...	...	...	...	...	...	...	0·0	0·05	0·07
Acetate . .	...	...	...	0·0	...	...	...	...	0·24	0·14

The water service committee of the American Railway Engineering Association[1] publishes a report containing the results of tests of the resistance to corrosion of various kinds of iron and steel.

L. C. Wilson[2] gives a general review of the nature and causes of corrosion of iron and steel, and of the means for its prevention.

D. M. Buck[3] deals with the prevention of corrosion in iron and steel products, and describes a number of tests to ascertain what influence a small content of copper in steel had on the rate of corrosion of the metal. The tests were made under actual service conditions on full-size sheets, and show the superiority of copper-bearing steel over ordinary steel in lessening the rate of corrosion.

S. Evans[4] describes and illustrates some cases of failure of metal in works' plant, and also refers to one or two cases of corrosion.

E. A. Richardson[5] has investigated the effect of the preliminary pickling or cleaning undergone by sheet iron on the subsequent corrosion, and finds that the method adopted has a decided influence on the rate of corrosion. This is particularly noticeable when a passifying agent such as nitric acid is used.

T. Herrmann[6] discusses the corrosive action of electrical currents on the gas and water mains in the town of Gablenz, Austria.

Corrosion of Boilers.—A. Heinzelmann[7] deals with a case of serious corrosion in boilers. The feed-water had a total hardness of 3·5° (German), the temporary hardness being only 1°. The water contained 3 grammes of SiO_2, and 3 grammes of nitrates per 100,000, chlorides being present in only very small amount. The boilers were worked at a pressure of 10 to 12 atmospheres, and considerable corrosion was produced. At the end of two months a hard crust, 6 millimetres in thickness, had formed, and the water blown off was found to be strongly acid. The crust contained 80 per cent. Fe_2O_3, and 6 per cent. alkali silicates. On the surface was a layer of calcium sulphate 1 millimetre in thickness. The action was due to the decomposition, under pressure, of the chlorides and nitrates by the silicic acid. The liberated mineral acids attacked the iron, and the resulting salts became hydrolysed, and a progressive rusting of the boiler thus occurred. The trouble was overcome by adding sufficient sodium hydroxide to the feed-water to keep the water in the boilers alkaline to phenolphthalein. This reaction between silicic acid and nitrates in boilers is considered to occur only at a pressure of nearly 10 atmospheres.

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[1] *Engineering News*, 1914, vol. lxxii. pp. 255 256.

[2] *Engineering Magazine*, 1914-15, vol. xlviii. pp. 517-523, 667-674, 849-858 *et seq.*

[3] *Mining and Engineering World*, 1914, vol. xli. pp. 749-753.

[4] *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. pp. 204-207.

[5] *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 759.

[6] *Journal für Gasbeleuchtung*, 1914, vol. lvii. pp. 88-89.

[7] *Chemiker Zeitung* (*Chemisch Technisches Repertorium*), 1914, vol. xxxviii. p. 376.

It is stated [1] that many cases of local corrosion of boiler tubes have been found to be due to the liberation of oxygen bubbles from the feed-water. These bubbles adhere to the walls of the tube, thus causing oxidation; and the oxygen from fresh feed-water is then liberated preferentially on the parts roughened by oxidation, thus accelerating the local corrosion.

Corrosion of Cast Iron and Steel Pipes.—An abstract is given [2] of a pamphlet recently issued by Stewarts & Lloyds, Limited, which gives some useful information on the subject of corrosion of steel and cast iron pipes. The process and effects of corrosion in cast iron and steel pipes are materially different. It is found by experience, particularly in the case of the interior surface of water pipes, that where the water is particularly soft a certain amount of corrosion does occur. In steel pipes this corrosion may attain a depth of half an inch, resulting in a nodular incrustation to a thickness of as much as an inch. Corrosion then practically ceases, the incrustation formed serving as an effectual preventive of further corrosion. In the case of cast iron the depth of corrosion may amount to $\frac{3}{8}$ths of an inch, with nodular incrustation to a depth of 2 inches before further corrosion is arrested by the protection afforded. In either case when this nodular incrustation is removed further corrosion occurs; but where many people have been misled is in the very different appearance of cast iron and steel on removal of the incrustation. The proportion of carbon in cast iron by volume is about 35 per cent.; whereas in steel it is only about 2 per cent. Any corrosion in steel is at once evident as pitting, but not so with the case of cast iron. The fabric of carbon left on the surface of a cast iron pipe so closely resembles cast iron in appearance that until a chisel is applied it may not be discovered that the pipe has corroded at all. With regard to protective coatings, experience has proved that a mixture of gas-tar and oil in the correct proportions is cheaper, and, properly applied, affords a protection as permanent and water-tight as those containing, in addition, a proportion of natural asphalt or such constituents as bitumen.

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[1] *Tätigkeitsbericht des Kgl. Materialprüfungsamtes zu Berlin-Lichterfelde*, 1913/1914; *Chemiker-Zeitung*, 1915, vol. xxxix. p. 71.

[2] *Iron and Coal Trades Review*, 1915, vol. xc. p. 215.

W. J. E. Binnie[1] deals with the corrosion of iron and steel pipes, with special reference to water pipes. He reviews the various theories to account for corrosion, and discusses the relative corrodibility of cast iron, wrought iron, and steel. With regard to protective measures, it has been found that the coating of Angus Smith's solution is a fairly efficient protection against corrosion. The original mixture consisted of coal-tar, tallow, slaked lime, fine resin, and coal naphtha; but the mixture used at the present time consists essentially of coal-tar and pitch oil in the proportion of two to one by bulk, and the pipes are dipped in this at nearly boiling temperature after all rust and scale have been removed. Large steel pipes used on certain lengths of the Catskill aqueduct for the water supply of New York have been given a 3-inch lining of two to one Portland cement mortar, and experiments have shown that even where the mortar has not adhered to the metal the desired protective action has been obtained.

The composition of cast iron pipe and the conditions contributing to corrosion are enumerated and discussed.[2]

Passivity of Iron.—In dealing with the question of passivity, B. Lambert[3] points out that the inactivity of pure iron is probably due to its having a physically homogeneous surface consisting of one form of the metal. In the case of ordinary commercial iron the presence of chemical impurities—chemical heterogeneity—makes it impossible to have a physically homogeneous surface, and in consequence there must always be a tendency for such metal to pass into solution in an electrolyte. When the metal is made passive, the passivity is confined to a very thin surface layer, which very easily undergoes disruption. Whatever be the chemical nature of the layer, the tendency for the metal to pass into solution at this surface, in an electrolyte, is enormously reduced, the surface of the metal having been rendered electrically equable. Passivity, then, may be defined as the production, by some chemical or electro-chemical process, of a physically homogeneous layer on the surface of a metal of which the surface was physically heterogeneous.

H. G. Byers[4] and S. C. Langdon refer to previous investigations, in which it has been shown that the establishment of the passive state in iron used as an anode is affected by the character and condition of the metal, the electrolyte, the temperature, the current density, the duration of passage of the current, and the character of movement of the electrolyte. They now describe experiments which indicate that another factor must be added to these, namely, the concentration of the dissolved oxygen about the anode, and that this is apparently the determining factor. When all these factors are taken into account, constant results can be obtained with respect to the time required to render iron passive with a given current in sulphuric acid, and a critical current density in nitric acid can be determined. Passivity, when not caused by a visible film of oxygen, is considered to be due to the fact that the rate of ionisation of certain metals is not sufficient to carry a current of more than a certain density. When such current density is exceeded, oxygen electrodes, consisting of occluded oxygen, are formed in electrolytes consisting of oxygen compounds. Non-anodic passivity is also regarded as due to occlusion of oxygen, and consequent protection of the metal from attack.

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[1] Paper read before the Institute of Sanitary Engineers; *Surveyor*, 1915, vol. xlv pp. 536–540.

[2] *Engineering Contractor*, vol. xlii. pp. 377–381.

[3] *Transactions of the Chemical Society*, 1915, vol. cvii. pp. 218–222.

[4] *Journal of the American Chemical Society*, 1914, vol. xxxvi. pp. 2004–2011.

F. Flade[1] and H. Koch state that when an iron electrode is placed in a 0·1 *N*-sulphuric acid solution and anodically polarised, a stationary condition sets in, in which a constant current passes, and the iron has a definite potential. Gradually changing the polarising potential causes the electrode potential to fall suddenly at a definite point, the value which it reaches representing a sharp transition from the active to the passive condition. The authors have investigated the influence of various substances on the stationary potential and the transition potential, and describe their results.

Protective Coatings for Iron.—H. A. Gardner[2] has carried out an investigation in order to ascertain the best type of paint for preventing the corrosion of iron embedded in concrete, caused by the action of stray currents of electricity. The author concludes that the vehicle of the paint should contain boiled or bodied oils or products which dry, by polymerisation rather than oxidation, to a fairly saturated film having a dull rather than a glossy surface. The solid portion of the paint should contain a percentage of pigments which are inert, electrically non-conducting, and coarse, in order to produce a film having a rough surface, and also pigments of the basic or chromate type. If possible, sand should be applied to the painted surface while it is still tacky, to improve the adhesion of the cement or concrete.

A. H. Sabin[3] reviews briefly the present situation as regards paints for structural steel, and his remarks form the basis of a lengthy discussion on the subject, to which contributions are made by A. S. Cushman, S. T. Wagner, H. A. Gardner, A. W. Carpenter, M. Toch, R. D. Coombs, and others.

Details are given[4] of numerous methods employed in Cleveland and Buffalo to protect the steel overbridges from corrosive and destructive blasts from locomotives.

H. B. C. Allison[5] and L. A. Hawkins describe a process discovered by T. Van Aller, of heating metals in revolving drums with mixtures containing finely-divided aluminium, by which a surface alloy containing aluminium is produced. Instances are given and illustrated in which iron and steel treated by this process has been subjected to a temperature of 900° for four hours without burning. The process would appear to be useful as a method of treating iron which is to be used under oxidising conditions at high temperatures.

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[1] *Zeitschrift für physikalische Chemie*, 1914, vol. lxxxviii. 307–320.

[2] *Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 313–336.

[3] *Transactions of the American Society of Civil Engineers*, 1914, vol. lxxvii. pp. 952-988.

[4] *Engineering News*, 1914, vol. lxxii. pp. 764–767.

[5] *General Electric Review*, 1914, vol. xvii. p. 947; *Iron and Coal Trades Review*, 1915, vol. xc. p. 86.

C. L. Lucas[1] describes the sherardising process, the apparatus and methods employed.

Laboratory Appliances.—W. Rosenhain[2] describes three instruments designed with a view to increasing the accuracy and convenience of research work. One is an optical device for the accurate levelling of metal specimens for the microscope. A beam of light reflected from the polished surface of the metal is used as an index, whereby the surface can be quickly and easily set horizontal. The other two instruments deal with problems which arise in the preparation of accurate heating and cooling curves. One of these problems is that of controlling the supply of heat, both during heating and cooling, so as to regulate the rate and make it as uniform as possible. This is attained by the use of vertical tube furnaces, so arranged as to be hot at one end and cold at the other, with a uniform gradation of temperature between the two ends; the specimen is raised or lowered in this tube, and heated or cooled accordingly, the rate being easily varied by altering the rate of raising or lowering. The third appliance is a "plotting chronograph" by means of which "inverse rate" curves are plotted automatically to a very large scale, the observer merely tapping a key as the various temperature intervals are passed.

O. Ruff[3] describes and illustrates an improved form of electric vacuum-furnace for high temperatures.

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[1] *Machinery*, 1915, vol. xxi. pp. 361–364.

[2] *Journal of the Institute of Metals*, 1915, No. 1, pp. 160–192.

[3] *Zeitschrift für Elektrochemie*, 1914, vol. xx. pp. 177–179.

CHEMICAL ANALYSIS.

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II. Analysis of Iron Ores, Slags, and Refractory Materials .	632	IV. Analysis of Gas . . .	636

I.—*ANALYSIS OF IRON AND STEEL.*

Estimation of Arsenic.—A. Kleine[1] gives a method for determining arsenic in iron, steel, and ores. The arsenic is distilled from the iron solution after having added 1 gramme of bromide of potash and 3 grammes of hydracine sulphate, which obviates the necessity of redistillation after adding fresh hydrochloric acid. The arsenic in the distillate is precipitated with sulphuretted hydrogen, which in contrast to other methods permits of judging the presence and quantity of the arsenic before titration. An apparatus for the performance of the operation is described.

Estimation of Carbon.—W. Brady[2] describes the method for the determination of carbon in steel by the direct combustion of the metal in oxygen. The carbon dioxide obtained is absorbed in a known excess volume of barium hydroxide solution. The precipitated barium carbonate and the excess barium hydroxide are rinsed into a flask, and the latter is titrated with standard hydrochloric acid, using phenolphthalein as an indicator. This titration, subtracted from a blank titration of the standard acid against the same volume of barium hydroxide used, gives a measure of the carbon converted to carbonate. The apparatus for carrying out the method is described in detail. As reagents Linde oxygen, standard hydrochloric acid, barium hydroxide solution, and phenolphthalein are used.

E. Szász[3] describes a rapid method for the estimation of carbon in iron and its alloys. An electrical crucible furnace is employed, and the boat containing the iron is placed in one end of a porcelain tube which is open at both ends. This tube is surrounded by a similar, slightly larger tube closed at the end, which is placed in the furnace; the space between the two tubes may contain a mixture of cobalt oxide and fireclay. The outer ends of the tubes are connected by a stuffing-box, and surrounded by a cooling jacket. The oxygen is supplied to the outer end of the inner tube, and the combustion gases leave the apparatus by a side-tube on the outer porcelain tube, and are conducted to the gas-measuring apparatus or to an absorption vessel. Dilute sulphuric acid (1 : 10) is used in place of mercury in the gas-measuring burette.

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[1] *Chemiker Zeitung*, 1915, vol. xxxix. p. 43.

[2] *Journal of Industrial and Engineering Chemistry*, 1914, vol. vi. pp. 843–845.

[3] *Journal of the Society of Chemical Industry*, 1914, vol. xxxiii. pp. 994–997.

The method is a modification of a previously described one, for which a costly and complicated apparatus was required. By the new method the apparatus becomes less complicated and much less costly.

W. D. Brown[1] gives a direct method for the estimation of carbon in iron and steel by combustion. The supply of oxygen is automatic. The method is exceedingly rapid, and can be used for the determination of carbon in steels ranging from 0·07 per cent. to 1 per cent. It can also be applied to the analysis of pig iron.

J. R. Cain[2] describes the barium-carbonate titration method for the determination of carbon in iron and steel.

The standard specifications of the American Society for Testing Materials for methods of chemical analysis for plain carbon steel are given.[3]

R. Lepsoe[4] states that de Nolly's method for the rapid determination of carbon in iron and steel gives very accurate results, and is suitable for the control of open-hearth and electric steel furnaces. It is applicable to all kinds of steel, 1–2 grammes of the same being mixed with 0·1–0·2 gramme of lead peroxide or bismuth-trioxide. Pig irons and ferro-alloys must be passed through 80-mesh and 120-mesh sieves respectively, and burnt off on a layer of 1–2 grammes of pure iron containing 0·05–0·08 per cent. of carbon.

J. Morsing[5] gives a very complete description of the apparatus used in the Swedish State Technical High School for determining the amount of carbon in iron and steel.

Estimation of Nitrogen in Steel.—L. E. Barton[6] describes A. H. Allen's method for the estimation of nitrogen in steel, as subsequently modified by J. W. Langley. This depends on the use of Nessler's solution, and its practical difficulty is that the standards prepared in the ordinary way never match the assay solutions satisfactorily, being orange-yellow in comparison with brownish-yellow. The modification now recommended overcomes the difficulty.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. p. 390.
[2] *United States Bureau of Standards: Technologic Paper*, No. 33.
[3] *Year-book of the American Society for Testing Materials*, 1914, pp. 169–176, 181–192.
[4] *Chemiker Zeitung*, 1914, vol. xxxviii. pp. 1137–1138.
[5] *Bihang till Jernkontorets Annaler*, 1914, pp. 77–94.
[6] *Journal of Industrial and Engineering Chemistry*, 1914, vol. vi. pp. 1012–1013.

Estimation of Phosphorus.—J. R. Cain[1] and F. H. Jucker describe a method for the determination of phosphorus in steels containing vanadium.

Estimation of Chromium in Steel.—H. Tusker[2] describes a rapid method for the determination of chromium in iron and steel. With steels containing manganese the quantitative ammonium persulphate method, in which the chromium oxide in a weak sulphuric acid solution is oxidised by means of persulphate of ammonium to chromic acid, is modified by adding a few drops of hydrochloric acid, which destroy the precipitated superoxide of manganese. In this way filtering can be dispensed with without causing a loss of chromic acid.

Estimation of Copper in Steel.—In view of the increased use of copper in steel as a preventive of corrosion and of the necessity of completing the estimation in a very short time, W. D. Brown[3] describes a rapid and accurate method for the determination of copper in steel.

Estimation of Nickel.—W. J. Marsh[4] describes his experiments made with a view to improving the process for the electrolytic estimation of nickel.

Analysis of Tungsten.—H. Arnold[5] continues his description of the analytical examination of commercial tungsten.

Analytical Operations.—G. Surr[6] points out some of the difficulties encountered in analytical operations.

W. R. Schoeller[7] gives a systematic outline of the course to be adopted in the analysis of inorganic and metallurgical substances.

Laboratory Appliances.—C. M. Johnson[8] describes the design and construction of an electrical muffle furnace for use in the determination of carbon and oxygen in steel and in tungsten powder. The advantages it possesses over the ordinary form of muffle furnaces are low first cost, ease of repair, quick heating and covering, and cleanliness.

II.—*ANALYSIS OF IRON ORES, SLAGS, AND REFRACTORY MATERIALS.*

Analysis of Iron Ore.—S. Wurzel[9] describes a device for the rapid evaporation of the solutions obtained in the determination of silica and alumina in iron ores. The difficulties caused by bumping can be obviated by using a ring of sheet tin ¾ inch high and 4⅜ inches in diameter as a support for the 5½-inch evaporating dish. The ring is placed directly on the hot-plate, so that the bottom of the dish does not touch the latter, and the effect of a hot-air bath on which evaporation will proceed under the boiling point of the solution is secured which conduces to more satisfactory manipulation and greater ease in final operations.

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[1] *United States Bureau of Standards: Technologic Paper*, No. 24.

[2] *Chemiker Zeitung*, 1915, vol. xxxix. p. 122.

[3] Paper read before the American Chemical Society, January 21, 1915; *Journal of Industrial and Engineering Chemistry*, 1915, vol. vii. p. 213.

[4] *Journal of Physical Chemistry*, 1914, vol. xviii. pp. 705–716.

[5] *Zeitschrift für anorganische Chemie*, 1914, vol. lxxxviii. pp. 333–340.

[6] *Mining and Engineering World*, 1914, vol. xli. pp. 1167–1168.

[7] *Analyst*, 1915, vol. xl. pp. 90–106.

[8] *Metallurgical and Chemical Engineering*, 1915, vol. xiii. p. 17.

[9] *Ibid.*, 1914, vol. xii. p. 430.

L. Tschugaeff[1] and B. Orelkin describe a sensitive reaction and colorimetric method for the determination of iron.

L. Vásárhely[2] states that since ferric oxide tends to be reduced partly to magnetite (Fe_3O_4) during ignition, owing to the reducing action of the carbon of the filter paper, he recommends that precipitates of hydrated ferric oxide obtained in the usual way should be ignited in a Rose's crucible in a current of oxygen.

Separation of Aluminium.—H. D. Minnig[3] describes a method of separating and estimating aluminium associated with iron by the action of acetyl chloride in acetone.

Estimation of Cobalt.—A. Metzl[4] describes a method for the volumetric estimation of cobalt in the presence of nickel.

Separation of Tungsten and Molybdenum.—E. E. Marbaker[5] describes a method for the separation of tungsten from molybdenum.

Separation of Vanadium and Phosphorus.—In dealing with the separation of vanadium and phosphorus with "cupferron," V. G. Rodeja[6] states that after reduction of the vanadate to the hypovanadate, the vanadium is quantitatively precipitated by freshly prepared "cupferron" solution, and the phosphate may be estimated in the filtrate.

Production of Metallic Tungsten.—P. C. H. West[7] describes in detail the various methods for the production of metallic tungsten. The several processes, as set forth in numerous British and American patent specifications, are enumerated.

G. Torossian[8] describes some modifications of the reduction test for tungstic acid.

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[1] *Zeitschrift für anorganische Chemie*, 1914, vol. lxxxix. pp. 401–404.

[2] *Zeitschrift für analytische Chemie*, 1914, vol. liii. pp. 688–690.

[3] *American Journal of Science*, 1915, 4th Series, vol. xxxix. pp. 197–200.

[4] *Zeitschrift für analytische Chemie*, 1914, vol. liii. pp. 537–541.

[5] *Journal of the American Chemical Society*, 1915, vol. xxxvii. pp. 86–95.

[6] *Anales de la Sociedad Española Fisica y Quimica*, 1914, vol. xii. pp. 379–382.

[7] *Journal of Chemical Technology*, 1915, vol. ii. pp. 102–106.

[8] *American Journal of Science*, 1914, 4th Series, vol. xxxviii. pp. 537–538.

Estimation of Iron in Basic Slag.—L. Blum[1] points out that basic slag often contains a proportion of vanadic acid, the presence of which is indicated by the blue colour of the solution which appears in determining the total phosphoric acid by the method of the German Chemists' Association. In estimating the iron in the slag, the vanadic acid content should be taken into account. An instance is given where it was found to amount to 1·55 per cent., and the method recommended for its determination is to determine the iron and vanadium together by titration according to Reinhardt's method, and then to treat another sample in the same way for vanadium alone. The difference gives the percentage of iron. A discussion of the subject follows the author's report.

Analysis of Basic Slag.—W. Holle[2] has made comparative trials of the accuracy of the methods of analysis of ground basic slag. The methods of Lorenz, Naumann, and Popp were examined. That of Lorenz gives the most exact results, but is more complicated than the other two.

Analysis of Magnesite.—A method for éstimating magnesia in magnesites is given by H. Udowis-Zewski,[3] by which the somewhat inaccurate results of Mayerhofer's method may be improved. The method, which involves the citric acid treatment and double precipitation, is conducted on a sample of the magnesite previously dissolved in aqua regia and evaporated to dryness.

Analysis of Clays.—A. B. Searle[4] discusses various methods of analysis of clays and siliceous rocks, pointing out the many difficulties which are frequently productive of errors in carrying out such analyses. The analysis of clays is usually limited to the determination of the constituents silica, alumina, ferric oxide, lime, magnesia, alkalies, loss of ignition, and moisture, but the constituents of any clay or siliceous rock are so numerous that it is impossible for the sum of those determined to add up exactly to 100, and where this does occur some compensation of errors will be found responsible. For the further investigation of many of the problems of furnace linings, it is necessary to know more of the proximate composition of the materials than is known at present. The chemist who can find a method of converting the highly complex alumino-silicic acids into definite salts which are readily separable from other silicates, will open up a vast field of important industrial research, which is at present closed owing to the fact that there are no means of completely isolating clays from their impurities, or vice versa.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 14–18.

[2] *Chemiker Zeitung*, 1914, vol. xxxviii. p. 1083.

[3] *Ibid.*, p. 949; *Engineering and Mining Journal*, 1914, vol. xcviii. p. 789.

[4] *Journal of Chemical Technology*, 1915, vol. ii. pp. 97–101.

III.—*ANALYSIS OF FUEL.*

Coal Sampling.—T. W. D. Gregory[1] deals with the taking and preparation of such samples of coal as are from time to time required in connection with colliery work.

A. C. Fieldner[2] gives some notes on the sampling and analysis of coal, which apply particularly to coal in place in a mine or outcrop, and are intended to supplement information already published by the Bureau of Mines.

Analysis of Coal.—S. W. Parr[3] and H. F. Hadley describe a method of coal analysis in which the cellulose and resinous substance are separated by the use of phenol as a solvent. With these subdivisions it is possible to make a more detailed study of the conditions which produce weathering and deterioration of coal, oxidation, and spontaneous combustion. The residue offers a better opportunity than has hitherto been available for studying the coking constituents and their behaviour under oxidation and distillation processes.

The soluble material also serves as an index to the type of coal, differentiating between varieties of bituminous coal more minutely than is possible with a simple volatile matter determination.

F. Weisser[4] describes a method for the determination of ash in coal and coke.

Estimation of Nitrogen in Coal and Coke.—A. C. Fieldner[5] and C. A. Taylor compare the various modifications of the Kjeldahl method with the Dumas method of estimating nitrogen in coal.

B. M. Margosches[6] discusses the various modifications of the Kjeldahl method for the estimation of nitrogen in coke.

Estimation of Water in Petroleum.—H. S. Shrewsbury[7] describes two rapid methods of estimating water in crude petroleum, oil fuel, and other similar substances. The first is an improved distillation process, the novelty of which is the apparatus, which is simple and effective. The second is the turbidity temperature process, which depends on (1) the possibility of extracting water from oil-fuel with glacial acetic acid; (2) the delicacy with which the turbidity temperature of glacial acetic acid and a standard oil responds to minute percentages of water.

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[1] Paper read before the North Staffordshire Mining Institute; *Iron and Coal Trades Review*, 1915, vol. xc. p. 779.

[2] United States Bureau of Mines, 1914: *Technical Paper*, No. 76.

[3] Illinois University Engineering Experiment Station, 1914, *Bulletin* No. 76.

[4] *Chemiker Zeitung*, 1914, vol. xxxviii. pp. 1264–1265, 1289–1290.

[5] Paper read before the American Chemical Society; *Journal of Industrial and Engineering Chemistry*, 1915, vol. vii. pp. 106–112.

[6] *Chemiker Zeitung*, 1915, vol. xxxix. pp. 167–168.

[7] *Analyst*, 1914, vol. xxxix. pp. 529–532.

IV.—*ANALYSIS OF GAS.*

Sampling and Analysis of Coal-Gas.—At a recent meeting of the American Gas Institute several papers dealing with the analysis of gas were read and reported.[1] Amongst these were the following: A report on methods of sampling gases, and ammoniacal liquor, coal and coke, by W. H. Fulweiler; a paper on the determination of hydrogen sulphide in gas, by A. B. Way; and a paper on the separation of the illuminants in mixed coal-gas and water-gas by G. A. Burrell and I. W. Robertson.

E. V. Evans[2] describes his method of eliminating carbon bisulphide from coal-gas. The method is based on the observation that most of the sulphur compounds in coal-gas are decomposed and converted into hydrogen sulphide (which is subsequently absorbed by iron oxide) when the gas is heated to 500° C.

Analysis of Flue-Gas.—G. M. Kohler[3] describes an inexpensive outfit for analysing flue-gas, by which an analysis can be made within five minutes with fairly accurate results.

Apparatus for Analysis of Complex Gas Mixtures.—G. B. Taylor[4] describes and illustrates an apparatus which, while embodying no novel principle, combines several old ones in such a manner that the United States Bureau of Mines recommend it not only for research, where great accuracy is required, but for many technical purposes where the slight loss of speed is more than compensated for by the increased accuracy of the results.

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[1] *Metallurgical and Chemical Engineering*, 1914, vol. xii. pp. 677–678.

[2] *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. pp. 9–14.

[3] *Power*, 1914, vol. xl. pp. 447–448.

[4] *Journal of Industrial and Engineering Chemistry*, 1914, vol. vi. pp. 845–848.

STATISTICS.

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I.—*UNITED KINGDOM.*

Mineral Statistics.—According to preliminary figures[1] the production of iron ore in the United Kingdom in 1914, apart from that obtained in quarries, was 8,984,492 tons, of which 7,241,481 tons were mined under the Coal Mines Act and 1,743,011 under the Metalliferous Mines Act. The output of coal in 1914 amounted to 265,643,030 tons. The output of other minerals included 3437 tons of manganese ore, 3,268,666 tons of oil shale, and 205 tons of tungsten ore.

The total output of the oil-shale industry of Great Britain in 1913 amounted to 3,280,143 tons, valued at £822,394.[2] The mineral is obtained chiefly in Edinburghshire and Linlithgowshire. The average yield of oil is 22 gallons and of sulphate of ammonia 45 lbs. per ton of shale.

Iron Trade Statistics.—The production of pig iron in the United Kingdom in 1913, according to official statistics,[3] amounted to 10,260,315 tons, and comprised the following :—

	Tons.
Hæmatite	3,604,823
Forge	1,300,787
Foundry	2,500,760
Basic	816,891
Ferro-chrome and ferro-silicon	26,653
Spiegeleisen and ferro-manganese	297,492
Iron sent in molten condition to steelworks	1,712,909
	10,260,315

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[1] Home Office: *Mines and Quarries: General Report with Statistics for* 1914 (advance proof).

[2] *Iron and Coal Trades Review*, 1915, vol. xc. p. 91.

[3] Home Office: *Mines and Quarries: General Report with Statistics for* 1913, Part III.

In the production 25,707,518 tons of iron ore and 21,223,607 tons of coal were used. During the year there were $337\frac{8}{12}$ furnaces in blast.

According to the British Iron Trade Association [1] the production of the different descriptions of pig iron in Great Britain during 1914 was as follows:—

	Tons.
Forge and foundry	3,430,448
Bessemer hæmatite	3,235,403
Basic	2,003,693
Spiegeleisen, ferro, &c.	336,354
	9,005,898

Of this total Scotland produced 1,140,354 tons, the North-East Coast 3,313,227 tons, and Cumberland and Lancashire 1,185,598 tons.

The British Iron Trade Association [2] give the following particulars relating to the production of steel in the United Kingdom during 1914:—

	Tons.
Acid Bessemer	797,072
Basic Bessemer	482,444
Acid open-hearth	3,680,848
Basic open-hearth	2,874,749
	7,835,113

E. Jüngst [3] discusses the iron ore supplies of Great Britain, and gives tables of the production, imports, and prices from 1875 to 1913. The countries whence iron ore and manganiferous and manganese ores are imported are stated, with the quantities imported from each, in 1909, 1912, and 1913.

Statistics of the British Empire.—Particulars are given [4] relating to the coal output of the British Empire during the period 1899 to 1913. During the fifteen years covered by the returns there was an increase of about 102,988,000 tons in the output of the Empire.

Particulars are given [5] of the value of the imports and exports of iron and steel throughout the British Empire during the fifteen years 1899 to 1913.

British Steelworks.—In the course of his presidential address to the Cleveland Institution of Engineers, Sir Thomas Wrightson [6] gave a short review of a number of the principal iron and steel making establishments in the Middlesbrough district.

Iron and Steel Trade Relations of Great Britain and Germany.—E. Jüngst [7] publishes statistics showing the total imports of iron and steel of all kinds to Great Britain and Germany from 1900 to 1913 inclusive, and also the imports and exports of iron from Great Britain to Germany and the same from Germany to Great Britain for the same period of years. The exports from both countries to the United States for the same period are also quoted. Another table gives the imports and exports of iron and pig iron alone and the exports of tinplate from Great Britain to Germany. In the author's opinion, which he bases on statistical evidence, the British imports of iron into Germany will cease after the war, while those of Germany to Great Britain are likely to be increased considerably.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 566. [2] *Ibid.*, p. 726.

[3] *Glückauf*, 1915, vol. li. pp. 42–50.

[4] Board of Trade: *Statistical Abstract for the British Empire.* [5] *Ibid.*

[6] *Proceedings of the Cleveland Institution of Engineers*, Session 1914–15, pp. 8–48.

[7] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1807–1810.

II.—*AUSTRALIA.*

Mineral Statistics of New South Wales.—The output of coal in New South Wales during 1914 was 10,390,622 tons. The coke made during the year amounted to 304,800 tons.[1]

Mineral Statistics of Queensland.—The following table[2] shows the mineral production of Queensland during 1913:—

	Tons.
Coal	1,037,944
Ironstone (flux)	40,838
Copper	23,655
Tin	3,197
Lead	3,603
Molybdenite	66
Limestone (flux)	161,165
Tungsten	359

Mineral Statistics of Tasmania.—According to the Department of Mines[3] the mineral production of Tasmania in 1914 included the following: 60,794 tons of coal and 47 tons of tungsten ore.

III.—*AUSTRIA-HUNGARY.*

Mineral Statistics.—According to official statistics published[4] by the Public Works Department the output of iron ore in Austria in 1913 was 3,039,324 tons, as compared with 2,926,686 tons in 1912. The production of manganese ore in 1913 was 16,540 tons and of tungsten ore 52 tons. The revised figures for the coal production in 1913 are as follows:—

	Tons.
Hard coal	16,459,889
Brown coal	27,378,332

It is stated[5] that the production of coal in Austria in 1914 suffered from the effects of the war and the shortage of rolling stock. The output, which was 15,073,132 tons, declined by 1,386,757 tons as compared with 1913; whilst the quantity of lignite decreased to 23,772,069 tons, as compared with 27,378,332 in 1913. The make of coal briquettes in 1914 was 194,221, and that of lignite briquettes 230,642 tons. The coke production totalled 2,189,913 tons, showing a decline of 394,000 tons.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 821.

[2] Queensland: *Annual Report of the Under Secretary for Mines*, 1913.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 636.

[4] *Stahl und Eisen*, 1914, vol. xxxiv. p. 1777.

[5] *Ibid.*, 1915, vol. xxxv. p. 177.

Iron Trade Statistics.—The official statistics of the production of pig iron in 1913[1] are as follows:—

	Tons.
Puddling pig iron	1,484,431
Foundry pig	273,433
Total production	1,757,864

The corresponding production in 1912 was 1,759,851 tons.

The production of steel in Austria-Hungary in 1914 was as follows.[2] The figures for 1913 are given for comparison.

	Acid Bessemer.		Basic Bessemer.	
	1914.	1913.	1914.	1913.
	Tons.	Tons.	Tons.	Tons.
Austria	604	843	159,500	232,900
Hungary	4,009	41,738	...	...
	4,613	42,581	159,500	232,900

	Open-hearth Steel.		Electric Steel.	
	1914.	1913.	1914.	1913.
	Tons.	Tons.	Tons.	Tons.
Austria	1,312,988	1,500,452	18,655	24,902
Hungary	607,361	749,711	1,189	1,935
Bosnia	28,520	33,656	...	...
	1,948,869	2,283,819	19,844	26,837

	Crucible Steel.		Puddled Iron and Steel.	
	1914.	1913.	1914.	1913.
	Tons.	Tons.	Tons.	Tons.
Austria	16,424	22,260	30,600	59,068
Hungary	1,133	2,903	9,776	12,251
	17,557	25,163	40,376	71,319

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. p. 1777.

[2] *Ibid.*, 1915, vol. xxxv. p. 275.

The output of steel rails in Austria-Hungary[1] in 1914, as compared with 1913, was:—

	1914.	1913.
	Tons.	Tons.
Austria	94,152	114,227
Hungary	97,235	141,470
	191,387	255,697

IV.—*BELGIUM.*

Iron Trade Statistics.—The production of pig iron in Belgium[2] during the first six months of 1914 amounted to 1,233,410 tons.

V.—*CANADA.*

Mineral Statistics.—The production of iron ore in Canada[3] in 1913, according to official statistics, amounted to 307,634 short tons, and comprised 92,386 tons of hæmatite, 209,886 tons of magnetite, and 5362 tons of titaniferous iron ore.

The production of coal in 1913 amounted to 15,012,178 short tons, as against 14,512,829 tons.

The total quantity of coke made in Canadian coke-oven plants during 1913 from both domestic and imported coals was 1,517,133 short tons, of which 67 per cent., or 1,018,632 tons, was made in by-product ovens.

The output of petroleum in 1913 was 228,080 barrels.

According to the official preliminary figures[4] the output of iron ore in Canada in 1914 was 244,854 short tons. The production of coal amounted to 13,594,984 short tons, and the production of petroleum to 214,805 barrels.

Mineral Statistics of Alberta.—The output of coal in Alberta, Canada, during the year 1913 is returned[5] at 4,306,346 tons, of which the bulk was exported to the United States. 65,167 tons of coke, the whole of which was consumed in Canada, were made during the year. The increased coal output during the year showed an advance of 24·95 per cent. over the output of the previous year, which was 3,446,349 tons.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. p. 276.

[2] Comité des Forges de France, 1915: *Bulletin* No. 3277.

[3] Canada, Department of Mines, Mines Branch, 1914: *Report* No. 320.

[4] *Ibid.*, 1915: *Report* No. 333.

[5] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 1783–1784.

Mineral Statistics of Nova Scotia.—The mineral production[1] of Nova Scotia during the year ended September 30, 1914, included the following:—

	Tons.
Coal	7,005,464
Coke	417,616
Pig iron	251,275
Steel ingots	305,194

Iron Trade Statistics.—The official report[2] on the mineral production of Canada shows that the pig iron production in 1913 amounted to 1,128,967 short tons, which does not include the output of ferro-alloys. The classification of the pig iron was as follows:—Bessemer, 265,685 tons; basic, 614,845 tons; foundry, including miscellaneous, 224,741 tons; and charcoal pig, 23,696 tons. The total production of ferro-alloys in electric furnace plants during 1913 was 8075 short tons.

The production of steel ingots and castings in 1913 was 1,168,993 tons, and comprised the following:—

	Tons.
Basic open-hearth ingots	824,818
Acid Bessemer	301,932
Open-hearth castings	39,217
Other steels	3,026

Complete statistics of the production of rolled products and of manufactured steel have not been received; returns from several of the largest producers, however, show a production of blooms, billets, slabs, &c., of 1,134,277 tons.

The preliminary report[3] issued by the Department of Mines shows that the production of pig iron in Canada in 1914 fell off over 30 per cent. compared with 1913. The total in 1914 was 783,164 short tons, which is the smallest output since 1909. Of this 9380 tons was made with charcoal and 773,784 tons with coke. The classification of production was as follows:—

	Tons.
Bessemer	230,817
Basic	346,553
Foundry and malleable	205,794

Most of the ore used was imported from Newfoundland, only 182,964 tons being the product of Canadian mines. The iron ore despatched from the mines of Canada in 1914 was 244,854 short tons. Ontario produced 556,112 tons of pig iron and Nova Scotia 227,052 tons. In 1914 Canada exported 19,063 tons of pig iron and imported 100,827 tons.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 570.

[2] Canada, Department of Mines, Mines Branch, 1914: *Report* No. 320.

[3] *Ibid.*, 1915: *Report* No. 333.

VI.—*FRANCE.*

Ironworks in the War Region.—A list of the principal iron ore mines and iron and steel works in the invaded territory of France is given,[1] accompanied by a map of the region.

Mineral Statistics of Algeria.—The production of iron ore in Algeria during 1913 was as follows:[2]—

	Tons.
From mines	264,319
From open workings	1,009,673

The exports of iron ore during the year totalled 1,363,400 tons, of which 790,641 tons were consigned to the United Kingdom, 84,631 tons to Germany, and 66,281 tons to Austria-Hungary.

VII.—*GERMANY.*

Mineral Statistics.—The iron ore production of Germany (including Luxemburg) in 1913 totalled 35,941,275 tons.[3] As regards districts, Luxemburg contributed 20·4 per cent. of the total, Lorraine 58·8 per cent., Berg and Siegerland 7·6 per cent., and Nassau-Oberhessen 3·1 per cent. Only 11 per cent. of the ores mined came within the Bessemer limit of 0·05 per cent. phosphorus. The details of the production were as follows:—

Kind of Ore.	Tons.
Minette (Lorraine)	21,136,265
Minette (Luxemburg)	7,333,372
Brown hæmatite, less than 12 per cent. manganese	3,005,970
Brown hæmatite, 12 to 30 per cent. manganese	330,037
Red hæmatite	1,102,067
Spathic ore	2,860,811
Miscellaneous	172,753

The following official figures[4] have been issued by the German Imperial Statistical Board in relation to the production of coal, coke, and briquettes in 1914:—

	Tons.
Coal	161,535,224
Lignite	83,946,906
Coke	27,324,712
Coal briquettes	5,948,929
Lignite briquettes	21,448,600

The output of coal declined by over 9½ million tons as compared with 1913; while that of lignite decreased by 3,170,000 tons, and that of coke by 4,850,000 tons.

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[1] *Iron and Coal Trades Review*, 1914, vol. lxxxix. pp. 285–286.

[2] *Ibid.*, 1915, vol. xc. p. 821.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1749–1750.

[4] *Ibid.*, 1915, vol. xxxv. p. 489.

Imports of Manganese Ore.—In concluding his article on the manganese and manganiferous ore resources of Germany, L. Scheffer [1] gives a table showing the total imports of manganese ore into Germany and the countries whence it was imported. The following extract shows the imports for the ten years ending 1912:—

Year.	Tons of Manganese Ore Imported.
1903	223,709
1904	255,760
1905	262,311
1906	331,171
1907	393,327
1908	334,133
1909	384,445
1910	487,872
1911	420,709
1912	523,132

In 1912 almost the whole supply was furnished from the four chief producing countries as under:—

	Tons.
Russia (including Siberia)	336,819
India	126,614
Spain	30,707
Brazil	20,857

Mineral Statistics of Alsace-Lorraine.—The iron ore output in Alsace-Lorraine showed a marked reduction during 1914, being only 14,021,279 tons, as against 21,135,554 tons in 1913.

The output of coal in 1914 was 2,856,780 tons, as against 3,795,932 tons in 1913.[2]

Mineral Statistics of Luxemburg.—The output of iron ore in Luxemburg in 1913 amounted to 7,333,372 tons, as against 6,533,930 tons in 1912.[3]

Iron Trade Statistics.—Statistics have been issued [4] giving particulars concerning the production of pig iron in Germany in 1914. In that year the output amounted to 14,389,852 tons, as compared with 19,309,172 tons in 1913, being a reduction of 4,919,320 tons. A declining period of prosperity was in evidence on the opening of 1914, the output in the first six months being 288,000 tons less than in the corresponding period in 1913. The following table shows the production in 1914 according to qualities:—

	Tons.
Foundry	2,494,832
Bessemer	237,988
Basic	9,289,989
Steel-making and spiegeleisen	1,996,786
Forge	370,257
	14,389,852

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[1] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1336–1341.
[2] *Ibid.*, 1915, vol. xxxv. p. 404.
[3] *Ibid.*, 1914, vol. xxxiv. pp. 1319–1320.
[4] *Ibid.*, 1915, vol. xxxv. pp. 227–229.

The production according to districts was as follows:—

	Tons.
Rhenish-Westphalia	6,610,119
Siegerland and Hessen-Nassau	702,741
Silesia	853,957
North and Central Germany	734,659
South Germany and Thuringia	266,065
Saar district	954,738
Lorraine and Luxemburg	4,267,573

A table is also given showing the course of production month by month during the last two years. The largest percentage decline in the production in 1914 took place in Bessemer pig iron, which decreased by 35·4 per cent.; whilst the falling off in foundry iron was 31·7 per cent. The greatest percentage diminution in districts occurred in Lorraine and Luxemburg, and amounted to 33·5 per cent.; the Saar district ranks second in this respect with a reduction of 30·3 per cent., and the Siegerland and Hessen-Nassau third with a decrease of 29·4 per cent.

According to the returns published by the Verein deutscher Eisen und Stahl Industrieller,[1] the production of steel in Germany in 1914 amounted to 14,973,106 tons, and comprised the following kinds:—

	Tons.
Basic Bessemer	8,169,183
Acid Bessemer	100,617
Basic open-hearth	5,946,215
Acid open-hearth	274,321
Basic steel castings	211,095
Acid steel castings	87,243
Crucible steel	95,096
Electric steel	89,336

The output divided according to districts was as follows:—

	Tons.
Rhenish-Westphalia	8,420,706
Silesia	1,173,066
Siegerland and Hessen-Nassau	306,399
North, East, and Central Germany	604,793
Saxony	259,695
South Germany	144,126
Saar and Bavaria	1,390,248
Alsace-Lorraine	1,513,844
Luxemburg	1,160,229

Particulars are given[2] of the report of the Stahlwerks Verband, which was issued recently, for the year ended June 30, 1914. This is the last official document issued by the Syndicate giving a record of the course of business under normal conditions down to a period of one month preceding the outbreak of war. The total deliveries between July 1, 1913, and June 30, 1914, amounted to 6,124,310 tons, considered as ingots, as against 6,514,081 tons in 1912–13.

Lists of the iron and steel products are published[3] the export of which is prohibited, and of those the exports of which to neutral countries is sanctioned by the German Government during the war until further notice.

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[1] *Stahl und Eisen*, 1915, vol. xxxv. pp. 378–381.
[2] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 727.
[3] *Stahl und Eisen*, 1914, vol. xxxiv. pp. 1491–1492.

German Steel Syndicate.—Particulars are given[1] of a new scheme which is being brought forward for the consolidation of the steel industry of Germany. It is proposed that the Association should be entitled the Ingot Syndicate, its object being to regulate the production of ingots of all kinds.

VIII.—*JAPAN.*

Iron Trade Statistics.—Statistics of the Japanese iron and steel trade in recent years are published.[2]

IX.—*RUSSIA.*

Mineral Statistics.—According to preliminary data[3] the output of coal in Russia in 1914 is estimated as follows:—

	Tons.
South Russia	27,600,000
Poland	3,870,000
Moscow District	300,000
Ural	1,480,000
Caucasus	80,000
	33,330,000

Figures furnished to the Coal Distribution Committee of the Russian Government show that the quantity of coal produced in the Donetz basin in 1914 amounted to 27,596,000 tons, including 5,000,000 tons of anthracite.[4]

The production of mineral oil in the several oil-fields of Russia in 1914[5] was as follows:—

	Tons.
Baku	7,087,000
Grosny	1,595,000
Ural	264,500
Maikop	64,500
Central Asia	30,500
	9,041,500

Mineral Resources.—C. R. King[6] gives an account of the chief mineral resources of Russia. The mineral regions of South Russia comprise the provinces of Ekaterinoslav, Kherson, Tauride, and the Don Government, covering an area of 335,000 square kilometres, which is more than the total area of England and Ireland, and over eleven times the area of Belgium. The products of these provinces are principally coal—bituminous and anthracite—iron ore and manganese, quartzites, dolomites, clays, and spathic limestones.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 149.

[2] *Glückauf*, 1914, vol. l. pp. 1521–1523.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 442.

[4] *Ibid.*, p. 397.

[5] *Ibid.*, p. 720.

[6] *Engineering Magazine*, 1914–15, vol. xlviii. pp. 481–492.

The whole of the South Russian coal-field is included in what is known as the Donetz carboniferous basin. The coal-seams are specially concentrated towards the central part of the area, and comprise twenty-five to forty workable seams in addition to 200 thin strata. The maximum thickness runs from 1·5 to 2 metres in general. The coal-field possesses greater advantages than those of other European countries on account of its shallow depth. The seams either crop out or lie close to the surface, and the Don coal has a calorific value almost equal to the best lump Monmouth. The resources are estimated at 17,000 to 18,000 million tons, of which 12,000 to 13,000 millions are anthracite and about 5000 millions are bituminous coal.

The principal iron-ore region of Krivoi Rog is about 300 kilometres to the west of the coal-fields and about 160 kilometres from the Black Sea, and is estimated to contain 206,370,000 tons up to a depth of 200 metres. The mining industry started in 1861, and the output in 1910 was about 4,200,000 tons. The conditions of the coal and iron trade are briefly considered, and great developments are thought to be assured after the war.

Iron Trade Statistics.—It is stated that the output of pig iron in Russia during 1913 is returned at 4,741,000 tons. The production of ingots and slabs was 5,094,000 tons, and iron and steel manufactures 4,210,000 tons.[1]

The production of pig iron in Russia during 1914 is estimated to be about 4,270,000 tons.[2]

According to the South Russian Metallurgical Statistical Bureau the pig iron output at South Russian works in 1914 amounted to 2,997,000 tons.[3]

Russian Iron and Steel Works.—A table is given,[4] compiled from official statistics, showing the number of iron and steel works in Russia together with particulars of blast-furnaces, converters, and open-hearth furnaces.

South Russian Iron Industry.—J. W. Revillon[5] describes the growth of the iron industry of South Russia. Notwithstanding the enormous mineral wealth, it was not until about the year 1870 that any really successful attempt was made to develop the iron industry in the district. In 1834 the production of charcoal iron in Russia, the only iron then made in the country, had reached 170,000 tons a year, and in spite of a prohibitive tariff on all imported iron, the yearly production up to 1851 only increased to 200,000 tons. After several unsuccessful attempts to smelt iron with mineral fuel in the South, a concession of about 1000 acres in the Donetz basin was granted to John Hughes, in 1869, on which to erect an ironworks. The New Russia Company was accordingly registered in England. At about the same time a furnace was built by Pastouhoff in the Don Cossack territory, to work on anthracite. It was not, however, until 1887 that this furnace began to make any appreciable quantity of iron. In 1887, stimulated by the example of the New Russia Company, which was then producing about 50,000 tons of pig iron per annum, and emboldened by the heavy import duty and the linking up by rail of the ore-deposits at Krivoi Rog with the Donetz coalfield, new capital was forthcoming for the erection of more ironworks. In that year the Alexandrovsk Works in Ekaterinoslav were started; two years later the Dnieprovienne Company opened their Kamenskvy Works; in 1902 the Krivoi Rog Iron Ore Company completed a blast-furnace near Krivoi Rog station, now known as the Gdantzev Works, and in 1894 the Droughkovka Works began operations. At the present time there are eighteen works in South Russia producing over 3,000,000 tons of pig iron a year, or about 70 per cent. of the total production of the country.

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[1] *Iron and Coal Trades Review*, 1915, vol. xc. p. 180.
[2] *Ibid.*, p. 442. [3] *Ibid.*, p. 397. [4] *Ibid.*, p. 538. [5] *Ibid.*, pp. 245–246.

F. Sandelin[1] gives a very complete account of the Russian iron industry, particularly in South Russia and the Ural district. The amount given shows a remarkable rise. From 1860 with an output of 322,000 tons it rose in 1910 to 3,040,000; the greatest being in the decade 1890–1900, from 904,000 in the former year to 2,896,000 in the latter.

X.—*SPAIN.*

Mineral and Iron Trade Statistics.—The mining and metallurgical industry of Spain for the year 1912 is reviewed.[2] The total iron ore raised in that year was 9,133,007 tons, of which there were exported to Great Britain 4,358,803 tons; and to Germany, 3,756,913 tons.

Official figures have recently been issued[3] relating to the production of coal and lignite in Spain during 1913. The following table shows the production of the different kinds:—

	Tons.
Coal	3,783,214
Anthracite	232,517
Lignite	276,791

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[1] *Bihang till Jernkontorets Annaler*, 1914, pp. 295–346.

[2] *Estadistica Minera d'Espana*, 1912.

[3] *Iron and Coal Trades Review*, 1915, vol. xc. p. 810.

The following particulars have appeared[1] relating to the output of iron ore and of iron and steel in Spain during 1913:—

During the year the make of coke amounted to 595,677 tons.

	Tons.
Iron ore	9,861,668
Iron pyrites	926,913
Manganese ore	21,594
Pig iron	424,774
Iron forgings	690
Steel ingots	61,943
Steel forgings	3,559
Rolled iron and steel	271,717
Finished steel goods	27,899

(The total make of steel of all kinds may be estimated at 365.118 tons.)

XI.—*SWEDEN.*

Mineral Statistics.—According to the official statistics recently issued by the Swedish Board of Trade,[2] the production of iron ore in 1913 amounted to 7,475,575 tons, and comprised 6,817,595 tons of first quality and other directly-usable ore and 657,976 tons of "slig." There was also produced 3822 tons of bog ore. The total number of iron ore mines operating in 1913 was 295. The production of coal in 1913 was 363,965 tons, and that of manganese ore 4000 tons.

Coal Supply of the Scandinavian Countries.—As is well known, the coal resources of the Scandinavian countries are very scanty. In Denmark in the middle of last century some small collieries on the island of Bornholm were worked for some years, but the enterprise could not continue, and no coal has since been worked in that country. Norway has no coal resources of any kind. In Sweden alone there is a coal-bearing district which is estimated to contain about 106,000,000 tons, and the yearly production is under 400,000 tons. In 1912 it amounted to 360,291 tons.[3] The consumption of coal in the three countries in 1912 was:—

	Tons.
Sweden	5,453,000
Norway	2,622,000
Denmark	4,075,000

Fully three-fourths of these quantities is imported from Great Britain, and in 1914 the imports remained unaffected in any way by the war.

Iron Trade Statistics.—In 1913 the production of puddled iron and ingot steel and castings in Sweden, according to the official figures,[4] was as follows:—

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[1] *Iron and Coal Trades Review*, 1915, vol. xci. p. 10.

[2] *Sveriges Officiella Statistik: Bergshantering berättelse för år* 1913.

[3] *Glückauf*, 1915, vol. li. pp. 91–94.

[4] *Sveriges Officiella Statistik: Bergshantering berättelse för år* 1913.

	Tons.
Puddled iron	158,472
Basic Bessemer ingots	70,770
Acid ,, ,,	44,803
,, ,, castings	266
Basic open-hearth ingots	276,983
Acid ,, ,,	177,860
Basic ,, castings	4,943
Acid ,, ,,	9,601
Crucible ingots	3,353
,, castings	32
Electric furnace ingots	1,926
,, ,, castings	350

During 1913 there were seventy-seven works producing puddled iron and ingot steel and castings.

The production of pig iron in 1913 was follows:—

	Tons.
Foundry and special pig	30,191
Bessemer and basic	500,078
Forge	186,090
Blast-furnace castings	13,898
	730,257

The total production included 31,966 tons of pig iron from one electric furnace. This furnace also produced 9863 tons of ferro-silicon, 1375 tons of ferro-silico-spiegel, 760 tons of ferro-chrome, and 136 tons of ferro-silico-manganese-aluminium alloy.

During the year 1913 there were in existence 148 blast-furnaces, of which 31 were out of blast.

The production of rolled and forged semi-manufactured iron and steel amounted to 431,548 tons in 1913, while the output of finished description amounted to 426,204 tons.

According to the report[1] of the Swedish Ironmasters' Association, the production of iron and steel in 1914 was as follows:—

	Tons.
Pig iron	635,100
Puddled blooms	113,300
Bessemer steel	93,000
Open-hearth steel	407,600

Swedish Iron Industry.—A. D. Udhaug[2] discusses the progress of the iron industry of Sweden. With the introduction of the Gröndal process of separating and briquetting, the resources of marketable ore in Central Sweden have increased by at least 100 million tons. During the period 1910–13 the annual production of briquettes amounted respectively to 248,900, 256,000, 289,000, and 333,000 tons, while the corresponding figures for "slig" were 366,000, 381,000, 521,000, and 658,000 tons. The number of blast-furnaces has shown a constant tendency to decrease since 1880, while the output has increased.

The small furnaces have rapidly disappeared to make room for larger ones. In 1883 the average production per furnace amounted to 10·24 tons per day, while in 1913 it had risen to 20·73 tons. The highest average figure is now 52 tons per day. The consumption of charcoal per ton of pig iron during the period 1910–13 declined in each year respectively from 62·8 to 61·2, 59·2 and 57·7 hectolitres. By the utilisation of calcined ore briquettes there has been effected a saving of fuel equal to about 12½ per cent. on the average. The manufacture of coke pig iron has been making good progress during recent years, and the output for the year 1913 was 101,000 tons, or more than three times as much as in 1909. The average consumption of coke per ton of pig iron was 1·14 ton.

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[1] *Bihang till Jernkontorets Annaler*, 1915, p. 75.

[2] *Iron and Coal Trades Review*, 1915, vol. xc. p. 407.

The electrical pig iron industry has been making still better progress, as the output was only 5800 tons in 1911, while in 1913 it was 32,000 tons.

XII.—*UNITED STATES.*

Mineral Statistics.—The estimated mineral production of the United States in 1914[1] is as follows:—

	Tons.
Anthracite coal	91,552,187
Bituminous coal	419,547,599
Coke	34,418,933
Iron ore	42,911,897

The following table[2] shows the production of crude metallic ores supplied from domestic mines to mills, concentrating plants, and smelters in the United States during 1913:—

	Short Tons.
Chromium ore	286
Tungsten ore	34,400
Titanium ore	7,600
Aluminium ore	235,470
Vanadium and uranium ore	27,900

According to the United States Geological Survey the production of tungsten ores in the United States during 1914 is estimated at about 990 short tons carrying 60 per cent. of tungsten trioxide. This output is the smallest since 1908, when only 671 tons were produced. In 1913 the production was 1537 tons.[3]

Statistics of the production of petroleum in Illinois in 1914 are given by R. S. Blatchley.[4] During the year 21,500,000 barrels were produced, as against 23,893,899 in the previous year. In Texas and Louisiana, according to A. J. Hazlett,[5] the productions were 20,586,377 and 16,860,235 barrels respectively. In California, according to M. L. Requa,[6] the total production was 100,093,568 barrels, not including oil used as fuel in the fields, which amounted approximately to 5,000,000 barrels.

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[1] *Engineering and Mining Journal*, 1915, vol. xcix. p. 45.

[2] *Iron and Coal Trades Review*, 1914, vol. lxxxix. p. 633.

[3] *Ibid.*, 1915, vol. xc. pp. 252.

[4] *Engineering and Mining Journal*, 1915, vol. xcix. pp. 136–137.

[5] *Ibid.*, pp. 137–139.

[6] *Ibid.*, pp. 139–140.

Iron Ore Reserves of the United States.—J. Birkinbine[1] has made a supplementary and revised estimate of the iron ore reserves of the United States, superseding that made by him in 1909. Most estimates of iron ore reserves assume that the present processes of smelting and conversion are to continue, but it is possible that within the next fifty years such changes may take effect as to render ores available that are not at present considered desirable.

Iron Trade Statistics.—According to the figures issued by the American Iron and Steel Institute,[2] the production of pig iron in 1914 amounted to 23,332,244 tons. In this total all pig iron and ferro-alloys are included, whether made in blast-furnaces or in electric furnaces. The various grades produced during 1914 are shown in the following table :—

	Tons.
Basic	9,670,687
Bessemer	7,859,127
Foundry	4,533,254
Malleable	671,771
Forge	361,651
Spiegeleisen	79,935
Ferro-manganese	106,083
All other	49,736

Forge quality alone showed an increase over the 1913 figures. The production of cold-blast charcoal pig iron in 1914 was 9294 tons, and hot-blast charcoal pig iron 254,630 tons. The production of pig iron according to fuel used was as follows :—

	Tons.
Coke	22,976,856
Anthracite	91,464
Charcoal	263,924

At the close of 1914 there were in existence 451 blast-furnaces, of which 287 were in blast and 164 out of blast.

According to the American Iron and Steel Institute[3] the output of rails in the United States in 1914 amounted to 1,945,095 tons, and comprised the following :—

	Tons.
Open-hearth	1,525,851
Bessemer	323,897
Re-rolled	95,169
Electric	178

The rails classed as "re-rolled" are those re-rolled from old steel and renewed rails which could not be classified as Bessemer or open-hearth. The following table gives the production of all kinds of rails in 1914, classified according to their weight per yard :—

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[1] *Bulletin of the American Institute of Mining Engineers*, 1914, pp. 2285–2292.
[2] American Iron and Steel Institute, Bureau of Statistics, 1915, *Bulletin* No. 1.
[3] *Ibid.*, *Bulletin* No. 2.

	Under 50 Lbs.	50 Lbs. and less than 85 Lbs.	85 Lbs. and over.
	Tons.	Tons.	Tons.
Open-hearth	96,068	211,414	1,218,369
Bessemer	78,280	97,063	148,554
Re-rolled	64,061	1,358	29,750
Electric	14	30	134
	238,423	309,865	1,396,807

Included in the above is the annual production of alloy-treated rails, shown separately in the following table;—

Total Production.	Produced by Alloys.		Produced by Processes.	
	Titanium.	Manganese and other Alloys.	Open-hearth and Electric.	Bessemer.
Tons.	Tons.	Tons.	Tons.	Tons.
27,937	23,321	4,616	27,447	490

The number of works rolling rails in 1914 was 24, of which 14 rolled open-hearth rails, nine rolled Bessemer rails, and one rolled electric steel rails, while 10 plants renewed rails and re-rolled old rails.

Official figures have been published[1] relating to the approximate production in the United States in 1913 of tubes, pipes, and sheets. Details are as follows:—

	Tons.
Wrought iron and steel tubes and boiler tubes	2,245,532
Hot-finished and cold-drawn seamless steel tubes	108,567
Iron and steel galvanised sheets	875,482
Cast-iron pipes and fittings	1,266,245

Consumption of Ferro-Silicon.—The total consumption of high-grade ferro-silicon, principally the 50 per cent. grade, in the United States is estimated at 13,000 to 15,000 tons annually. A little over 50 per cent. of this is produced by domestic electrolytic manufactures, the remainder being imported. In 1914 the imports from Canada amounted to 3981 tons, which was the largest amount from any outside source.[2]

Statistics of American Foundries.—On August 1, 1914, the total number of plants in the North American Continent engaged in the production of castings (including aluminium) was 6507, as compared with 6538 on July 1 in the previous year. In 1914 there were 299 steel foundries in the United States and 19 in Canada, the number corresponding with those in operation in 1912. The special types of foundries are classified according to the nature of the castings produced, and the output in tons given for each category.[1] A number of statistical maps are also reproduced.

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[1] American Iron and Steel Institute, Bureau of Statistics, 1914, *Bulletin* No. 10.
[2] *Iron and Coal Trades Review*, 1915, vol. xc. p. 637.

XIII.—*COMPARATIVE TABLES.*

World's Production of Coal, Iron, and Steel.—For purposes of comparison the following tables showing the production of coal, iron ore, pig iron, and steel in the principal countries of the world are appended :—

Production of Coal (in Tons).

Country.	1912.	1913.	1914.
	Tons.	Tons.	Tons.
United Kingdom	260,416,338	287,430,473	265,643,030*
Austria, coal	15,591,119	16,459,889	15,073,132
,, lignite	26,487,005	27,378,332	23,772,069
Belgium	22,983,460	22,858,450	......
Canada	14,512,829	15,115,089	13,594,984*
France	40,560,000	40,129,410	29,786,505*
Germany, coal	177,094,917	191,511,154	161,535,224
,, lignite	82,339,583	87,116,343	83,946,906
Holland	1,725,394	......	......
India	14,706,339	15,486,318	......
Japan	19,794,870	21,300,000	......
Russia	28,802,592	33,335,000*	33,330,000*
Spain	3,852,329	3,783,214	......
United States	534,466,580	562,069,806	511,099,786*

* Estimated.

Production of Iron Ore (in Tons).

Country.	1911.	1912.	1913.
	Tons.	Tons.	Tons.
United Kingdom	15,519,424	13,790,391	15,997,328
Austria	2,765,815	2,926,686	3,039,324
Canada	210,344	175,000	307,634
France	16,408,000	18,800,000	21,714,000
Germany	29,879,353	27,199,944	35,941,275
India	366,180	580,029	......
Italy	373,786	582,066	603,116
Russia	6,856,000	8,077,000	......
Spain	8,773,691	9,133,007	9,861,668
Sweden	6,153,778	6,178,516	7,475,571
United States	43,550,633	55,150,147	61,770,478

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[1] *Foundry; Iron Trade Review*, 1914, vol. lv. pp. 631–635.

Production of Pig Iron (in Tons).

Country.	1912.	1913.	1914.
	Tons.	Tons.	Tons.
United Kingdom	8,751,464	10,481,917	9,005,898
Austria-Hungary	1,863,769	1,757,864	......
Belgium	2,344,910	2,476,700	......
Canada	1,014,587	1,128,967	783,164 *
China	......	......	......
France	4,871,992	5,311,316	......
Germany	17,852,571	19,291,920	14,389,852
Italy	379,989	426,755	385,114
Russia	4,197,638	4,547,000	4,270,000 *
Spain	403,243	424,774	......
Sweden	701,900	735,000	635,100
United States	29,726,937	30,966,301	23,332,244

Production of Steel (in Tons).

United Kingdom.

Year.	Bessemer.		Open-hearth.		Total.
	Acid.	Basic.	Acid.	Basic.	
	Tons.	Tons.	Tons.	Tons.	Tons.
1905	1,396,233	577,977	3,042,834	795,238	5,812,282
1906	1,307,149	600,189	3,378,691	1,176,245	6,462,274
1907	1,280,315	578,944	3,384,780	1,278,709	6,522,748
1908	906,466	572,073	2,578,840	1,238,263	5,295,642
1909	1,111,042	622,178	2,763,158	1,385,250	5,881,628
1910	1,138,103	641,012	3,016,830	1,578,536	6,374,481
1911	887,767	573,373	3,131,118	1,869,354	6,461,612
1912	980,662	541,825	3,365,570	1,908,087	6,796,144
1913	1,048,772	551,929	3,811,382	2,251,793	7,663,876
1914	797,072	482,444	3,680,848	2,874,749	7,835,113

Austria-Hungary.

Year.	Bessemer.		Open-hearth.	Crucible.	Electric.	Total.
	Acid.	Basic.				
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1905	45,334	235,540	1,154,372	24,074	...	1,459,320
1906	50,789	256,537	1,274,131	26,125	...	1,607,552
1907	47,876	263,486	1,395,724	23,215	...	1,730,301
1908	52,829	271,253	1,670,275	19,659	4,333	2,018,349
1909	44,977	237,448	1,655,211	16,083	9,048	1,962,767
1910	34,874	297,500	1,803,829	17,586	20,028	2,173,817
1911	34,358	293,700	1,979,902	17,467	22,867	2,348,294
1912	52,845	347,100	2,261,139	25,438	21,556	2,707,078
1913	42,581	232,900	2,283,819	25,163	26,837	2,611,300
1914	4,613	159,500	1,948,869	17,557	19,844	2,150,383

* Estimated.

Belgium.

Year.	Bessemer.	Open-hearth.	Castings.	Total.
	Tons.	Tons.	Tons.	Tons.
1903	...	...	...	981,370
1904	...	...	...	1,083,000
1905	1,095,880	104,550	26,680	1,227,110
1906	1,277,010	118,130	45,720	1,440,860
1907	1,289,750	176,960	54,900	1,521,610
1908	1,070,840	127,160	51,620	1,250,620
1909	1,470,400	109,950	52,040	1,632,390
1910	1,755,500	136,660	52,660	1,944,820
1911	1,971,760	156,410	64,460	2,192,630
1912	2,252,380	190,040	72,620	2,515,040

Canada.

Year.	Acid Bessemer.	Basic Open-hearth.	Other Steels.	Castings.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.
1903 . . .	...	...	...	...	203,296
1904 . . .	...	...	...	...	166,381
1905 . . .	...	...	...	...	451,863
1906 . . .	...	...	...	...	639,396
1907 . . .	225,989	459,240	1,151	20,602	706,982
1908 . . .	135,557	443,442	713	9,051	588,763
1909 . . .	203,715	535,988	1,003	14,013	754,719
1910 . . .	222,668	580,932	599	18,085	822,284
1911 . . .	209,819	651,676	740	13,982	876,215
1912 . . .	207,569	617,061	400	28,001	853,031
1913 . . .	301,932	824,818	3,026	39,217	1,168,993

*France.**

Year.	Bessemer.		Open-hearth.	Crucible and Electric.	Total.
	Acid.	Basic.			
	Tons.		Tons.	Tons.	Tons.
1904 . . .	1,334,798		745,756	...	2,080,354
1905 . . .	119,526	1,345,511	775,247	...	2,240,284
1906 . . .	108,037	1,418,525	834,815	...	2,371,377
1907 . . .	78,771	1,669,757	1,001,463	16,782	2,766,773
1908 . . .	77,581	1,632,296	1,002,798	14,951	2,727,657
1909 . . .	76,981	1,853,327	1,080,912	23,351	3,034,571
1910 . . .	81,293	2,131,676	1,148,548	28,792	3,390,309
1911 . . .	75,158	2,389,352	1,185,345	30,758	3,680,613
1912 . . .	73,917	2,664,610	1,302,462	37,363	4,078,352
1913 . . .	76,816	2,931,072	1,368,067	43,286	4,419,241

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* Statistics collected by the Comité des Forges de France.

Germany.

Year.	Bessemer.		Open-hearth.		Castings.	Crucible.	Electric.	Total.
	Acid.	Basic.	Acid.	Basic.				
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1905	424,196	6,203,706	165,930	3,086,590	186,431	...	...	10,066,553
1906	407,688	6,772,804	230,668	3,534,612	189,313	...	...	11,135,085
1907	387,120	7,212,454	212,620	4,039,940	211,498	...	...	12,063,632
1908	374,100	6,510,754	146,768	3,854,155	192,883	88,183	19,536	11,186,379
1909	151,148	7,517,451	228,798	3,844,139	206,456	81,069	17,773	12,049,834
1910	171,108	8,060,571	140,189	4,973,569	263,811	83,202	36,188	13,698,638
1911	187,359	8,640,164	281,877	5,501,147	269,372	78,760	60,654	15,019,333
1912	187,079	9,794,300	194,924	6,650,565	321,663	79,190	74,177	17,301,998
1913	155,138	10,629,697	270,826	7,339,314	362,916	99,173	101,755	18,958,819
1914	100,617	8,169,183	274,321	5,946,215	298,338	95,096	89,336	14,973,106

Italy.

Year.	Steel not Classified. Total, Tons.
1904	201,148
1905	270,199
1906	390,740
1907	430,000
1908	537,000
1909	661,569
1910	732,000
1911	736,000
1912	917,911
1913	917,500

Russia.

Year.	Steel not Classified. Total, Tons.
1904	2,700,000
1905	2,208,000
1906	2,431,000
1907	2,600,000
1908	2,628,000
1909	3,071,000
1910	3,479,000
1911	3,870,000
1912	4,498,193
1913	4,827,240

Spain.

Year.	Bessemer.	Open-hearth.	Other Kinds.	Total.
	Tons.	Tons.	Tons.	Tons.
1907	135,148	161,000	1,500	297,684
1908	144,510	155,000	1,850	301,360
1909	148,479	158,000	2,000	309,479
1910	154,201	160,000	2,100	316,301
1911	155,581	165,000	2,400	322,981
1912	...	...	...	317,880 *
1913	...	...	...	365,118 *

* Estimated.

Sweden.

Year.	Bessemer.		Open-hearth.		Crucible and Electric.	Total.
	Acid.	Basic.	Acid.	Basic.		
	Tons.		Tons.		Tons.	Tons.
1905	78,204		288,975		1,319	368,198
1906	84,633		311,485		1,457	397,525
1907	77,036		341,893		1,287	420,216
1908	38,331	42,723	149,947	205,450	1,169	437,617
1909	29,026	34,325	100,987	147,770	927	313,035
1910	44,150	53,433	146,510	225,941	2,215	472,249
1911	41,116	52,737	148,323	224,383	4,309	470,867
1912	43,317	63,937	160,418	243,700	3,941	515,313
1913	45,069	70,770	187,461	281,926	5,661	590,887
1914	93,000		407,600		...	500,600*

* Estimated.

United States.

Year.	Bessemer.	Open-hearth.		Crucible.	Electric, &c.	Total.
		Acid.	Basic.			
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1904 . .	7,859,140	801,799	5,106,367	83,391	9,190	13,859,887
1905 . .	10,941,375	1,155,648	7,815,728	102,233	8,963	20,023,947
1906 . .	12,275,830	1,321,653	9,658,760	127,513	14,380	23,398,136
1907 . .	11,667,549	1,270,421	10,279,315	131,234	14,075	23,362,594
1908 . .	6,116,755	696,304	7,140,425	63,631	6,132	14,023,247
1909 . .	9,330,783	1,076,464	13,417,472	107,355	22,947	23,955,021
1910 . .	9,412,772	1,212,180	15,292,329	122,303	55,335	26,094,919
1911 . .	7,947,854	912,718	14,685,932	97,653	31,949	23,676,106
1912 . .	10,327,901	1,139,221	19,641,502	121,519	21,162	31,251,303
1913 . .	9,545,706	1,255,305	20,344,626	121,226	34,011	31,300,874

Coal Resources of the World.—D. B. Dowling[1] describes briefly the coal resources of the world. It is estimated that the world's available reserve of coal amounts to 7,397,553 million tons.

World's Production of Manganese.—An article is published[2] on manganese, its uses, production, imports, exports, and the war. All the principal sources of manganese ore in the world are enumerated. The principal localities in this country in which manganese ore occurs are in Wales, Cornwall, and Derbyshire, but in recent years the total output has been below 5000 tons. The world's production of manganese ore at present ranges from 2 million to 2¼ million tons, of which about 49 per cent. comes from Russia. The output is distributed as follows, according to the most recently available figures:—

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[1] *Transactions of the Canadian Mining Institute*, 1914, vol. xvii. pp. 374–405.

[2] *Engineering*, 1915, vol. xcix. pp. 9–10.

	Tons.
Russia	987,724
India	674,315
Brazil	163,506
Germany	75,787
Austria	17,717
Spain	16,678
Turkey	14,123
Japan	10,955
Greece	10,581
Hungary	10,410

Other countries produce smaller amounts.

Statistics of Great Britain's imports and exports of manganese ore for the years 1912, 1913, and 1914 are given, the figures for the last year showing the effect of the war upon the quantities imported and exported. In conclusion, the names of the more important manganese ores are given, together with their composition and percentage of manganese. Commercial manganese ores are those which contain about 35 per cent. and upwards.

W. W. Hearne[1] discusses the ferro-manganese position in America so far as it has been affected by the war. He enumerates the principal countries of origin, both of ferro-manganese itself and of the manganese ore necessary for its production. Efforts will probably be made to utilise the great known resources of Brazil to supply the deficiencies from other countries.

World's Production of Petroleum.—R. Kissling[2] reviews the petroleum industry of the world for the years 1912–1913. The refining and the various processes for the treatment of the oil are principally dealt with.

World's Production of Metals.—The world's production of the common metals, including aluminium and nickel, is given[3] for the year 1913, with the comparative figures for 1912. The average price per ton is also stated.

B. Neumann[4] reviews the metal industry for the year 1913. The world production and consumption of lead, copper, tin, and zinc is tabulated. Other metals are also enumerated. Details of the production of the various countries are given and average prices of the metals.

The production of copper in the world during the years 1912, 1913, and 1914 is given.[5] In 1914 it amounted to 893,085 tons.

In dealing with the question of iron as a factor in the world's progress J. Birkinbine[1] discusses the relative positions of the leading countries which produce pig iron or supply the requisite raw materials for its manufacture. He gives tables showing the production of iron ore, pig iron, and coal in the eight principal countries of the world from 1870–1913 by the ten-year periods.

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[1] *Iron Trade Review*, 1914, vol. lv. pp. 494–495.

[2] *Chemiker Zeitung*, 1914, vol. xxxviii. pp. 1284–1286, 1290–1293, 1373–1376.

[3] *Stahl und Eisen*, 1914, vol. xxxiv. p. 1321.

[4] *Glückauf*, 1915, vol. li. pp. 6–11, 38–42, 60–66.

[5] *Iron and Coal Trades Review*, 1915, vol. xc. p. 714.

The Iron Industry as affected by the War.—E. Schrödter[2] reviews the position of the iron and coal industries of the principal countries as at the end of January 1915, and the manner in which they had up to that date been affected by the war. He notes particularly that the Belgian iron industry is almost totally paralysed, and its condition will become more hopeless according as the war is prolonged. The author also claims in the case of France that the area occupied by the German forces includes nine-tenths of the French iron-ore resources. All the iron mines therein are being worked under the management of a board of German ironmasters. Out of 170 blast-furnaces it is computed that 127 were in blast about the beginning of 1914, and of this number 95 are in the occupied area. Since the largest and most modern are included in these 95, it is assumed with satisfaction that at least 80 per cent. of the French iron-smelting industry and 70 per cent. of the steel-making plants are shut down. The ruin of other industries such as the engineering, the textile, and the glass industries is also noted with complacency. The conditions of British industry appear to be scarcely well enough known to enable the author to present a clear picture, and he contents himself with arguments in proof of the complete incapacity of our iron industry to hold its own in the world. This would be the most desirable eventuality, and in second place a day of "personal reckoning" with the British ironmasters is looked forward to. The depressing effect of the war upon the American iron industry is next referred to, and the cupidity of American manufacturers in taking orders for munitions of war at a time when their trade with Germany is hindered is severely criticised.

The German iron industry has borne the stress of war remarkably well, and by the end of December had partially recovered from the set-back it received in August. The following figures of the output of pig iron show the position:—

	1913.	1914.
	Tons.	Tons.*
July	1,648,818	1,561,944
August	1,640,016	586,661
December	1,611,250	853,881

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[1] *Journal of the Franklin Institute*, 1915, vol. clxxix. pp. 470–488.
[2] *Stahl und Eisen*, 1915, vol. xxxv. pp. 125–140.

T. Good[1] discusses the future of the steel trade. Prior to the outbreak of hostilities the world's total export trade in iron and steel manufactures thereof amounted to about 18,000,000 tons a year. Continental Europe was exporting about 10,000,000 tons of iron and steel annually, of which Germany was responsible for 6,000,000 tons. In 1913 the German exports of iron, steel, and other metals and metal goods actually reached a value of £95,000,000; while their exports of machinery, &c., amounted to £57,000,000. The United States has lately been producing between 25 and 30 million tons of iron a year, and Germany has been making between 16 and 18 million tons a year, against 9,000,000 tons produced in this country.

Statistics of Electric Steel Furnaces.—A table is published giving[2] the number of electric steel furnaces in all countries. On January 1, 1915, there were in operation or building the following furnaces:—

	No. of Furnaces.
Heroult	75
Girod	28
Induction	36
Stassano	19
Keller	6
Chaplet	5
Electrometals	4
Hiorth	1
Nathusius	2
Rennerfeldt	18
Grönwall	2
Special	17
	213

Timber Imports.—E. Jüngst[3] gives comprehensive statistics of the imports and consumption of timber for mine supports in Germany and Great Britain. The imports into Great Britain in 1913 were 3,451,328 loads. Seven countries contribute to supply this amount, of which Russia sends the largest share (1½ million loads), France taking second place. On the basis of the figures the author strongly advocates the German authorities to declare timber absolute contraband of war.

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[1] *Cassier's Engineering Monthly*, 1915, vol. xlvii. pp. 73–6.
[2] *Iron Age*, 1915, vol. xcv. pp. 94–98.
[3] *Glückauf*, 1914, vol. l. pp. 1494–1499.

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DEC 17 1915

Printed by BALLANTYNE, HANSON & Co.
Edinburgh & London

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